

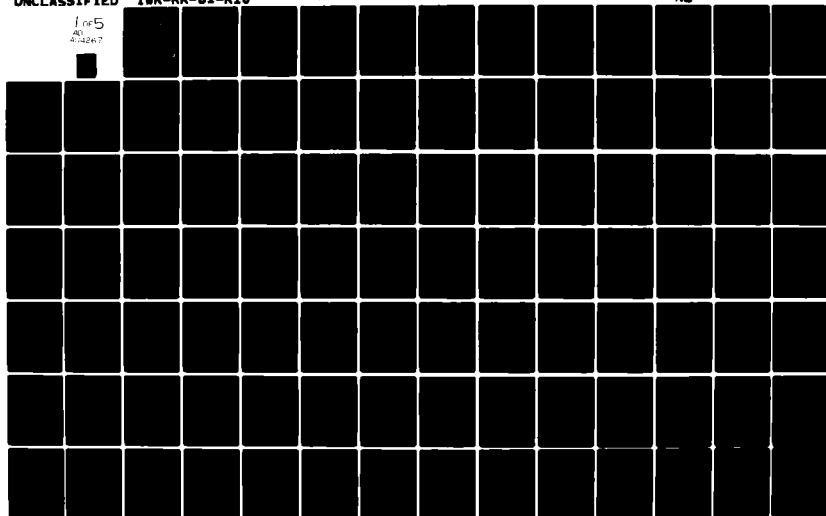
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SELECTED WORKS IN WATER SUPPLY, WATER CONSERVATION AND WATER SU--ETC(U)
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**US Army Corps
of Engineers**

Engineer Institute for
Water Resources

Selected Works in Water Supply, Water Conservation and Water Quality Planning

Water Conservation and Supply Information
Transfer and Analysis Program

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REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER IWR Research Report 81-R10	2. GOVT ACCESSION NO. AD-A114 267	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) Selected Works in Water Supply, Water Conservation and Water Quality Planning		5. TYPE OF REPORT & PERIOD COVERED Final
7. AUTHOR(s) Edited by: James E. Crews James Tang		6. PERFORMING ORG. REPORT NUMBER
9. PERFORMING ORGANIZATION NAME AND ADDRESS U.S. Army Corps of Engineers Institute for Water Resources Ft. Belvoir, Virginia 22060		8. CONTRACT OR GRANT NUMBER(s)
11. CONTROLLING OFFICE NAME AND ADDRESS U.S. Army Corps of Engineers Institute for Water Resources Ft. Belvoir, Virginia 22060		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		12. REPORT DATE May 1981
		13. NUMBER OF PAGES 444
		15. SECURITY CLASS. (of this report) Unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE
16. DISTRIBUTION STATEMENT (of this Report) Approved for public release; distribution unlimited		
17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)		
18. SUPPLEMENTARY NOTES		
19. KEY WORDS (Continue on reverse side if necessary and identify by block number) Water Supply; Conservation; Selected Works		
20. ABSTRACT (Continue on reverse side if necessary and identify by block number) The selected papers presents some of the more significant IWR research, during the 1970's concerning water supply, water conservation and water quality planning.		

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SELECTED WORKS IN WATER SUPPLY, WATER CONSERVATION
AND WATER QUALITY PLANNING

Water Conservation and Supply
Information Transfer and Analysis Program

May 1981

U.S. Army Corps of Engineers
Water Resources Support Center
Institute for Water Resources
Ft. Belvoir, Virginia 22060

May 1981

Research Report 81-R10

PREFACE

The Institute for Water Resources (IWR) was established in 1969 to enhance the capability of the Corps of Engineers to develop and manage the Nation's water resources, within the scope of the Corps responsibilities, by developing improvements in planning. In support of Corps programs and activities which are increasingly involved with water supply and water quality management, the Institute has undertaken a research program since its inception to address many aspects in water supply and quality management. The overall objectives of the research are to gain a better understanding of the major problems and opportunities related to water supply and quality management and to find better ways to solve the problems and capture the opportunities. In addition to the research program, the Institute's Policy Studies program continues to address water supply and conservation related issues and the Institute has conducted conferences on water supply and water quality management with wide participation from outside the government, and has held training seminars on water supply and water conservation planning and on water reuse.

A water supply and conservation Information Transfer and Analysis Program has been established at the Institute to disseminate technology transfer and provide one-stop information assistance. This document represents the first output of that program.

Although the Institute's research program addresses primarily the needs of Corps planners, the outcome of the research should be of interest to others who share a common concern of the nation's water supply and quality problems. The Institute, therefore, presents its research results in the form of articles written by individual authors for the Institute on the subject of water supply, water quality, and conservation planning, in this volume of selected works.

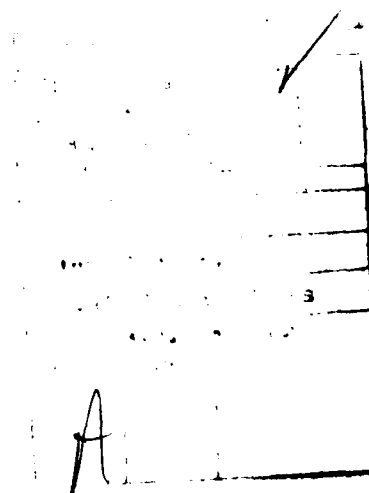


TABLE OF CONTENTS

	<u>PAGE</u>
Preface	1
Introduction	1
Information Transfer and Analysis Program	2
Milestones in IWR Contributions	4
Organization of the Reader	7
Planning Concepts and Approaches	8
Water Supply and Quality Planning	9
Water Reuse	9
Water Demand Forecast and Analysis	9
Drought Management	10
Water Conservation in Water Supply Planning	10
Urban Water Supply	11

LIST OF PAPERS

<u>PAPER</u>	<u>AUTHOR</u>	<u>PAGE</u>
Water Supply and Water Quality Studies in the Institute For Water Resources	Robert H. Harrison	15
Integrating Water Quality and Water and Land Resources Planning	David J. Allee, <u>et.al.</u>	103
Interregional Planning of Water Supply	Jay C. Andersen	137
Regional Analysis in Planning for Water Supply Extension	Stephen P. Coelen	143
Efficiency in Inter-Basin Water Transfers	John E. Keith	151
Integrating Ground and Surface Water Supply- Experience in the Humid Regions of the U.S.	Gert Aron and Walter Stottman	161
Water Control Management for Water Supply	Vernon K. Hagen	175
Water Supply in Relation To Quality: The Federal Aspect	James H. McDermott, Jr.	187
Quality Parameters in Water Supply Planning	Eric D. Bovet	203
The Northeastern United States Water Supply (NEWS) Study	Francis M. McGowan	213
Water Supply Planning Experience; Washington, D.C. Area	James E. Crews	225
Water Supply Planning in Arid Regions - Experience in the Middle Rio Grande Basin	William K. Johnson	239

LIST OF PAPERS (Continued)

<u>PAPER</u>	<u>AUTHOR</u>	<u>PAGE</u>
Chloride Control of Water Supply in a Semiarid Area and a Plan for Chicago to Reduce Storm Water Damage and Improve Water Quality	Carl H. Guam	247
Costs and Effects of a Water Quality Program for a Small Strip Mining Company	Lloyd G. Antle	265
Planning for Water Reuse	Duane D. Baumann	271
Municipal Reuse of Wastewater	Duane M. Dworkin	289
Interpreting Public Attitude Toward Water Reuse	John H. Sims	297
Assessing the Agricultural Demand for Water	Jay C. Andersen	305
The Requirement for Disaggregate Forecasts	John J. Boland	317
Changing Water-Use in Industry	Robert A. Leone	339
Evaluating Economic Risks in Water Supply Planning	G. K. Young	353
Community Response and Change in Residential Water Use to Conservation and Rationing Measures: A Case Study - Marin Municipal Water District	Frank H. Bollman Melinda A. Merritt	365
Corps of Engineers Initiatives In Water Supply	Donald B. Duncan	401
Urban Water Supply Planning	Duane D. Baumann John J. Boland	415
A Procedures Manual for Evaluating Water Conservation Planning	James E. Crews Kyle E. Schilling	425
Urban Water Systems: Problems and Alternative Approaches to Solutions	Kyle E. Schilling	439

SELECTED WORKS IN WATER SUPPLY, WATER CONSERVATION AND WATER QUALITY PLANNING

INTRODUCTION

Since the inception of the Institute for Water Resources (IWR) in 1969, the field of water supply and water conservation planning and technology has been rapidly changing. This document compiles some of the more significant IWR work in the decade of change (1970-1980).

The Institute's work reflects the fact that the Corps of Engineers is not a novice in the business of providing water supply for municipal and industrial (M&I) use. The first general authority for inclusion of water supply storage in Corps projects was enacted in 1958; however, storage for water supply was authorized in projects prior to 1958 on the basis of individual project proposals. Today, approximately eight million acre-feet of storage in 24 projects is under contract. An additional twelve million acre-feet of storage in 84 projects is either included in existing projects or will become available if all authorized projects are constructed.

Title I of Public Law 89-298, 1965 authorized a Federal and non-federal cooperative study to prepare plans to meet the long-range water needs of the Northeastern United States. The legislation also authorized Federal construction and operation and maintenance of certain major facilities that had previously been the responsibility of non-federal interests. This study has produced several water supply proposals; however, the appropriate Federal role in implementing these plans has not yet been established.

A new era in water supply planning began with President's Carter's announcement in May 1977 that water conservation would be the cornerstone of his revised water policy. A comprehensive review of water policy was initiated during the summer of 1977 that culminated in the President's Water Policy Message of June 6, 1978, and by a series of directives to the Federal agencies in July 1978.

Recognizing that increased attention needed to be devoted to water conservation as a part of water supply planning, the Corps initiated efforts to integrate water conservation into its activities in March 1978. The strategy called for the Corps to:

1. Define water conservation within the context of the Corps program;
2. Develop a plan of action for integrating water conservation into all aspects of the Corps program; and,
3. Develop principles and specific procedures for evaluating water conservation as part of M&I water supply.

The Corps issued its first plan of action (POA) on May 8, 1979, and a revised edition one year later. The POA addressed the relationship of water conservation to the planning of projects and their subsequent construction, operation and maintenance, as well as the regulatory program.

The President's water policy message also resulted in the formulation of the President's Intergovernmental Water Policy Task Force. The Subcommittee on Urban Water Supply of the Task Force was chaired by the Secretary of the Army. The Subcommittee produced a report on 6 June 1980 evaluating urban water supply problems and addressed potential policy or program changes at the Federal, state, or local level to solve these problems.

The Congress has also taken a special interest in the water supply problems facing the Nation. Numerous bills were introduced in the 96th Congress that would have, if enacted, modified the Corps' role related to water supply and conservation. The impact of these proposed changes would have extended the direct Federal assistance role in all facets of water supply augmentation, treatment, and distribution.

Additional work to move beyond this past decade is needed and continues as a part of a focused Corps of Engineers water supply/conservation research subprogram.

Before embarking upon this treatise, however, a look into future IWR and other Corps laboratories research and development programs will provide some insights into the increasing importance of water supply/conservation efforts in the Corps of Engineers.

INFORMATION TRANSFER AND ANALYSIS PROGRAM

At the direction of the Office of the Chief of Engineers, IWR has established and begun to implement an information exchange program dedicated to developing a water supply and conservation Information Transfer and Analysis Program (ITAP) to assist the Corps field agencies by technology transfer and one-stop assistance requests. As such, this Reader represents the first major output of the ITAP program.

The Institute for Water Resources has been designated as the principal in coordinating ITAP activities among Corps of Engineers R&D performing elements. The participating Corps of Engineers R&D performing elements and their respective areas of responsibility are as follows:

Institute for Water Resources
Hydrologic Engineering Center
Waterways Experiment Station

Planning Methodologies
Hydrologic Analysis Techniques
Technological Applications

Briefly outlined below are the research studies being conducted or planned:

Institute for Water Resources

- Case studies to illustrate the application of the procedures manual in incorporating conservation alternatives at the survey scope level of detail.

- An assessment of municipal and industrial water use forecasting approaches designed to explicitly complement equal consideration of both supply and demand management techniques. Procedures will be developed to assist in disaggregating forecasts of water demand data necessary to fully evaluate the application of conservation measures.
- Identify and analyze the short- and long-term socio-economic effects of water conservation technologies on households and communities of various socio-economic configurations.
- Studies to: (1) assess the methodologies for forecasting the effectiveness of water conservation measures; (2) assess the effects of price elasticities on water systems and their associated impacts; (3) assess the impacts of water conservation on water system costs dependability; and (4) determine the need for computerized procedures for determining impacts on water system costs and dependability.
- Develop technical manuals, guidance, training, and information transfer on planning and evaluating surface and groundwater supply alternatives

Hydrologic Engineering Center

- Developing analytical methods and procedures for determining the potential of surface and groundwater resources to meet present or future water supply needs.
- Evaluation of existing groundwater recharge analytical models.

Waterways Experiment Station

- Adapt MAPS (Methodology for Areawide Planning Studies Computer Program) for water conservation and water treatment applications.
- Develop procedures for the preliminary design and cost evaluation of water treatment, transmission, and distribution facilities that will be applicable to urban/regional studies.
- Develop technical guidance in the management, operation, maintenance, rehabilitation, and repair of water treatment and distribution systems for urban and rural communities.

The Corps is a unique organization whose responsibilities have evolved over a long history of service. The technical expertise of the Corps has been used in the broadening Federal interest in water resources, natural disaster and emergency activities, and special missions. There is no reason to believe that the role of the Corps in water resources will remain static, but the exact nature of future change is uncertain. Potential changes relate to the Federal role in water supply are under active consideration in both the Executive and Legislative Branches. Additional time will be required before the complex critical issues

associated with this question can be resolved and the Federal role for the future established. In the meantime, this reader and continuing research as part of the Corps of Engineers Information Transfer and Analysis Program for water supply/conservation, represents the best efforts of the Corps of Engineers laboratories to better prepare the Corps field agencies for the future.

MILESTONES IN IWR CONTRIBUTIONS

To provide a better understanding of IWR research activities in the past decade, activities including their outcome both in terms of chronological events and in terms of research subject matters or problems are presented. First, significant milestones are discussed. Following this, a brief section on how the reader is organized.

1970

The Role of the US Army Corps of Engineers in Water Quality Management.

IWR Report 71-1. Written by David J. Allee and Burham H. Dogde. This report evaluated the role in which the Corps of Engineers might contribute to the Federal program for solution of the nation's water quality management problem by utilizing its broad planning capability, nationwide organization, and established Congressional authorization and review procedures.

1971

Costs and Effects of Water Quality Program for a Small Strip Mining Company. IWR Report 71-7. This report represented an effort to approach the issues evolving from environmental quality goals through analysis of the potential range of impacts of these goals on a business firm: in this case, a small strip mine operating in southwest Ohio.

1972

A Methodology for Assessing Economic Risk of Water Supply Shortages. IWR Report 72-6, by G. K. Young, et al. This report developed a procedure for estimating income losses, to a defined region, associated with varying degrees of water shortages, resulting in a frequency-loss function. An empirical test of the procedure was developed for York, Pennsylvania.

1974

Six reports related to water supply planning were published during this year.

A Study of How Water Quality Factors Can Be Incorporated into Water Supply Analysis. IWR Report 74-2 (Three volumes bound in one). This study examined the feasibility of embedding quality parameters explicitly in water supply analysis by employing a microeconomic approach and using constrained optimization.

A Method for Integrating Surface and Groundwater Use in Humid Regions. IWR Report 74-3. This report examined and quantified the role of ground-water in future allocations of surface water storage for water supply. It identified the circumstances under which integrated use of ground and surface water may be desirable in humid regions such as Appalachia. The report developed a methodology for analysis and included a case study.

Interregional Planning of Water Resources Allocations by Systems Analysis Approach. IWR Report 74-4. This study developed a methodology for determining optimal allocations of water in Utah, given alternative assumptions and constraints. The application of a supply and demand model for water in Utah was the conceptual framework for the study. The complexity of the problem dictated the use of mathematical programming techniques using computer technology. The intent of the study was to determine the effectiveness of the approach, as well as generate information and analyses useful to public decision-makers involved in water resource planning in Utah. The report has four supplements:

No. 1: Water Resources Planning to Satisfy Growing Demand in an Urbanizing Agricultural Region. The report discussed the theory of demand for irrigation water and included an empirical application of linear programming to the estimates of irrigation water demand of the Jordan River Basin of Utah.

No. 2: Development of Regional Supply Functions and a Least-Cost Model for Allocating Water Resources In Utah: A Parametric Linear Programming Approach. This report developed supply functions for agricultural and Municipal or Industrial use in ten hydrologic study units in Utah by parametric linear programming. The shadow price of imported water to each study unit was determined to show possible economic consequences of inter-basin transfer. The primary factor affecting interbasin transfer of Colorado River water is the degree to which evaporation occurs from Great Salt Lake.

No. 3: The Economic Efficiency of Inter-basin Agricultural Water Transfers in Utah: A Mathematical Programming Approach. The report examined the efficient allocation of water in time periods up to the year 2020 under several alternative assumptions and calculated the cost of alternative policies.

No. 4: The Demand for Agricultural Water in Utah. This report provided some of the economic data necessary for sound decisions in the development and use of Utah's water resources with respect to agriculture.

Changing Water Use in Selected Manufacturing Industries. IWR Report 74-10. The report contributed to the understanding of some changes in the cost and quality of water on technological process design and plant location decisions. Geographic patterns of industry location appear to be shifting toward areas more favorably endowed with water resources. Regional and temporal variations in the recirculation of water were documented. The findings suggested that water for industrial processing is unlikely to be a major location determinant; rather, water for transporation may be a more important determinant.

An Evaluation of Water Reuse for Municipal Supply. IWR Report 74-11. In this report a simulation model for evaluating the economic efficiency of water reuse was formulated and applied to a single community. The nature and role of professional bias in the decision-making process in water reuse planning was also described.

Evaluation of Quality Parameters in Water Resource Planning. IWR Report 74-13. This report reviewed water quality from the standpoint of determining the influence of water contaminants on various uses of water; the technology and cost of water supply purification; the technology and cost of waste and recycling water; the benefits from enhanced water quality; economic techniques for optimal water supply purification and allocation; and for optimal waste and recycling water purification.

1975

A five day training seminar on water reuse planning was held in July in Indianapolis, Indiana attended by twenty Corps planners. A 222 page seminar proceedings was published in January 1976.

A three day water supply and water quality conference was held in December in Georgia. It was attended by 170 persons, many of whom were from local and state governments as well as private consulting firms. A conference proceedings was published.

Economic Concepts and Techniques Pertaining to Water Supply, Water Allocation, and Water Quality. IWR Paper 75-P5. This paper presented in a systematic manner, economic concepts and techniques helpful in analyzing alternative solutions to problems commonly found in planning water supply and water quality. Materials were compiled from IWR contract reports and related studies.

1977

IWR staff directed an interagency staff effort of the White House's Drought Study Group to assess the extent, severity, and impact of the 1977 drought.

IWR staff prepared a report entitled "Urban Studies Program Evaluation" for the Office of the Chief of Engineers. The urban studies program evolved and expanded originally from the Corps pilot wastewater management studies program, and the report identified some of the water supply issues being surfaced through the urban studies program.

Economic and Technical Considerations of Regional Water Supply. IWR Report 77-7. This report examined the theory and practices of regionalized small water supply systems. It also investigated the case for regionalizations based on the concern of water supply shortages. This was followed by a critical look at interbasin water transfer and its problems. The report found that in addition to institutional and political constraints, most regionalization plans failed because the problems of efficiency and equity are not resolved.

1978

A training course entitled "Economic, Social, and Institutional Aspects of Water Supply Planning" was given to about thirty Corps planners in March in Albuquerque, New Mexico.

IWR staff participated with the Water Resources Council to develop "Subpart C - NED Benefit Evaluation Procedures - Municipal and Industrial (M&I) Water Supply" of the Procedures for Evaluation of National Economic Development (NED) Benefits and Costs, Water Resources Planning, (Level C) for evaluating water supply.

1979

An Annotated Bibliography on Water Conservation. IWR Report 79-3. The bibliography was compiled from both published and unpublished conservation literature providing an annotated description of each, including references. The Bibliography represents one of three reports prepared by IWR for the Intergovernmental Task Force established pursuant to the President's Water Policy message to Congress in 1978. The two other reports were published in 1980 and are discussed below.

IWR staff participated in a conference on water conservation sponsored by the Engineering Foundation Conference, and held in Rindge, New Hampshire.

1980

IWR staff led an intergovernmental staff of the Subcommittee on Urban Water Supply, in the preparation of the Subcommittee report, An Analysis of the Nation's Urban Water Systems: Characteristics, Investment Requirements and Policy Options, as part of the President's Intergovernmental Water Policy Task Force.

The Evaluation of Water Conservation for Municipal and Industrial Water Supply, A Procedures Manual. IWR Report 80-1. This report described the concepts, procedures, and measurement techniques which can be used in developing and evaluating water conservation proposals applicable to municipal and industrial uses of water.

ORGANIZATION OF THE READER

The Reader is comprised of articles written for the Institute in the past decade on various topics dealing with water supply, water conservation, and water quality planning. Since these articles were written over the span of more than a decade and scattered in many IWR research reports, studies, and conference proceedings, this document represents an attempt to assemble them in a convenient package arranged in proper categories to provide a cross-sectional view of the Institute's research accomplishments.

The papers are organized into sections within the water supply, conservation and quality planning framework. The articles presented were written by IWR personnel, personnel of other government agencies, or consultants. They are either by-products of a major study, report supported by IWR, or contributions

to conferences or seminars sponsored in most cases by IWR. These articles cover in varying degrees all the IWR published reports on water supply planning as described under the preceding section "Milestones" except the 1970 report, The Role of the U.S. Army Corps of Engineers in Water Quality Management and the 1974 report, A Study of How Water Quality Factors can be Incorporated into Water Supply Analysis.

The following gives a brief description of each article contained in each section including the title of the article, the author, the date, and brief comment where appropriate.

Planning Concepts and Approaches

1. "Water Supply and Water Quality Studies in the Institute for Water Resources," 1976. Robert W. Harrison. While the article was originally intended to provide an overview of IWR research in water supply and quantity planning, later sections of the paper are devoted to the discussion of the need for broadening the planning concept to consider quality planning, conjunctive use of groundwater, and regionalization and comprehensive planning. Includes an excellent bibliography.

2. "Integrating Water Quality and Water and Land Resources Planning," by David J. Allee, et al, July 1977. Proceedings from a conference at Asilomar Conference Center, Pacific Grove, California, January 1976, sponsored by the Universities Council on Water Resources.

3. "Interregional Planning of Water Resource Allocations by Systems Analysis Approach," John E. Keith, et al, July 1974. The article summarizes IWR Report 74-4, Interregional Planning of Water Resources Allocations by System Analysis.

4. "Development of a Regional Analysis for Water Supply and Water Quality Planning," by Stephen P. Coelen, July 1977. The article highlights the findings of IWR Report 77-7, Economic and Technical Consideration of Regional Water Supply.

5. "Efficiency in Inter-Basin Water Transfer," by John E. Keith, July 1974. The article is based on Supplement 3 to IWR Report 74-4.

6. "Integrating Ground and Surface Water Supply - Experience in the Humid Regions of the U.S.," by Gert Aron and Walter Stottman, March 1978. A paper based on IWR Report 74-3, A Method For Integrating Surface and Groundwater Use In Humid Regions, and presented at a seminar held in Albuquerque, New Mexico.

7. "Water Control Management for Water Supply," by Vernon K. Hagen, March 1978. Article discusses how to consider water supply storage in reservoir management.

Water Supply and Quality Planning

8. "Water Supply in Relation to Quality: the Federal Aspect," by James H. McDermott, Environmental Protection Agency. A paper presented at the Albuquerque Conference, 1978.

9. "Quality Parameters in Water Supply Planning," by Eric D. Bovet, March 1978. A lecture based on IWR Report 74-13, Evaluation of Quality Parameters in Water Supply Planning.

10. "The Northeastern United States Water Supply (NEWS) Study," by Francis McGowen. From a paper presented at the Conference on Water Supply and Quality Planning, Atlanta, Georgia, December 1975.

11. "Water Supply Planning Experience, Washington, D.C. Area," by James E. Crews, March 1978. Observations of a water supply planning situation in the metropolitan Washington, D.C. area.

12. "Water Supply Planning in Arid Regions - Experience in the Middle Rio Grande Basin," by William K. Johnson, March 1978. This paper discusses some of the problems in planning water supply for an arid region.

13. "Chloride Control for Water Supply in a Semiarid Area and a Plan for Chicago to Reduce Storm Water Damage and Improve Water Quality," by Carl H. Guam. Paper discusses two Corps projects. Presented at the Water Supply Planning Conference in Atlanta, Georgia.

14. "Costs and Effects of a Water Quality Program for a Small Strip Mining Company," by Lloyd G. Antle, March 1978. An informal discussion of some of the findings from the IWR Study and Report 71-79, Costs and Effects of Water Quality Program for a Small Strip Mining Company.

Water Reuse

15. "Planning for Water Reuse," by Duane D. Baumann.

16. "Municipal Reuse of Wastewater," by Duane M. Dworkin.

17. "Interpreting Public Attitude toward Water Reuse," by John H. Sims.

These three articles were presented at the Water Supply Planning Conference in Atlanta, Georgia, 1975. For fuller treatment of water reuse, see IWR Report 74-11, An Evaluation of Water Reuse for Municipal Supply, also, Water Reuse, a report of the Proceedings of a seminar held in Indianapolis, Indiana, July 1975.

Water Demand Forecast and Analysis

18. "Assessing the Agricultural Demand for Water," by Jay C. Anderson. Presented at the Atlanta Conference in 1975, the article is based on Supplement 1 to IWR Report 74-4, Interregional Planning of Water Resources Allocations by Systems Analysis Approach.

19. "The Requirement for Disaggregate Forecasts," by John J. Boland, October 1980. This paper was presented at the October 1980 American Society of Civil Engineers (ASCE) Fall Convention, held in Hollywood, Florida. This paper discusses the requirements for and analyses of disaggregate forecasts in water supply planning.

20. "Changing Water Use in Industry," by Robert A. Leone. The article was presented at the Atlanta Conference and is based on IWR Report 74-10, Changing Water Use in Selected Manufacturing Industries.

Drought Management

21. "Evaluating Economic Risks in Water Supply Planning," by G. K. Young. Paper was presented at the Albuquerque Conference in March 1978 and is based on IWR Report 72-6, A Methodology for Assessing Economic Risk of Water Supply Shortages.

22. "Community Response and Change in Residential Water Use to Conservation and Rationing Measures: A Case Study -- Marin Municipal Water District," by Frank H. Bollman and Melinda A. Merritt. This paper was presented at the Albuquerque Conference and is based on a study conducted for the State of California.

Water Conservation in Water Supply Planning.

Since 1978 the Institute has focussed its research effort on water conservation in support of President Carter's water policies. As mentioned earlier, three reports were published: (a) The Role of Conservation in Water Supply Planning, April 1979, IWR Report 79-2, which is a policy paper; (b) An Annotated Bibliography on Water Conservation, April 1979, IWR Report 79-3; and (c) The Evaluation of Water Conservation for Municipal and Industrial Water Supply: Procedures Manual, April 1980, which is used by Corps planners.

These new water conservation efforts by the Corps are the subject of the two following articles:

23. "Corps of Engineers Initiatives in Water Supply," by Donald B. Duncan. This paper was presented at the Annual ASCE Meeting in Hollywood, Florida, in October 1980. The Corps' program in water supply is presented.

24. "Urban Water Supply Planning," by Duane D. Baumann and John J. Boland. A reprint from Water Spectrum, Fall, 1980. The meaning of conservation in relation to water supply and types of conservation measures are briefly discussed.

25. "A Procedures Manual For Evaluating Water Conservation Planning," by James E. Crews and Kyle E. Schilling. This paper was presented at the National Water Conservation Conference - Publicly Supplied Potable Water in Denver, Colorado in April 1981. The Corps principles and procedures for evaluating water conservation are discussed.

Urban Water Supply

The Institute has actively participated in the work of the Subcommittee on Urban Water Supply of the President's Intergovernmental Water Policy Task Force and as a result, has contributed two reports on urban water supply systems mentioned earlier. These two reports are: (a) An Analysis of the Nation's Urban Water Systems: Characteristics, Investments and Policy Options, February 1980; and (b) Urban Water Systems: Problems and Alternative Approaches to Solutions, June 1980. Major findings of these two reports were summarized in the following paper:

26. "Urban Water Systems: Problems and Alternative Approaches to Solutions," by Kyle E. Schilling, as presented at the Annual Conference of the New England Water Works Association meeting in September 1980.

PLANNING CONCEPTS AND APPROACHES

WATER SUPPLY AND WATER QUALITY STUDIES
IN THE INSTITUTE FOR WATER RESOURCES
U.S. ARMY CORPS OF ENGINEERS

Robert W. Harrison
Institute for Water Resources

I n t r o d u c t i o n

Scope and Character of IWR Studies

Although national policy specifically recognizes a federal interest in water supply and quality management to assure supply adequate in quantity and quality for urban and rural withdrawal and stream flow needs, water supply problems and the closely related aspect - water quality - hold an ambiguous position in the array of water problems commonly emphasized in federal-state plans for comprehensive development of the nation's water resources. Long considered essentially local in character, there is generally little appreciation of the aggregate problem created by uncertainty and insufficiency of supply and variations (and possibly deterioration) in quality. Regional analysis of the water resource has been uneven and undertaken with mixed objectives. On the other hand, local communities have frequently shown a remarkable ability to improvise and compromise with the supply problem, and sometimes the quality problem. This has led to the need for emergency actions in a few cases and has sometimes been potentially dangerous to public health and welfare. With the passage of the Federal Water Pollution Control Act and Amendments, there has been an

increased awareness of the water quality problem in all parts of the nation, but only a limited understanding has developed of the relationship between water supply management and water quality management. This arises from the fact that water supply management is carried out through a distinctive set of institutions and water quality management through another. The limited overlap in the execution of these responsibilities severely limits the extent of coordination and integration between water supply and water quality problems.^{1, 2}

One of the major challenges for today's water resource planner is to help forge the links needed to join the supply and quality aspects of water resource planning so that both supply and quality may be viewed as elements in the multiple-use approach to comprehensive river basin planning and development.

¹The dichotomy between local, regional and national interests and programs and between the accepted ways of handling closely related problems in the water resource field prompted David K. Hartley and others to observe: "It is perhaps a commentary on the pluralism and fragmentation of American policy making that we must research our policies and programs at all levels of government in order to determine what they are and what their impact on the pattern of national and regional development has been." From the "Regional Impacts of Federal Policy," by David K. Hartley, Janet W. Patton, Lucia F. Findley, for the Academy for Contemporary Problems published in A National Public Works Investment Policy, Background Paper, prepared for the Committee on Public Works, U.S. House of Representatives, 93rd Congress, 2nd Session Work, 1974, p 91.

²The University Council on Water Resources, The U.S. Water Resources Council, and the Environmental Protection Agency held a conference on this topic at Asilomar Conference Center, Pacific Grove, California, January 11 to 16, 1976.

The studies of water supply and water quality conducted in the Institute for Water Resources are intended to illuminate those dimensions of the planning for water supply and water quality which need strengthening in the program of the Corps of Engineers. The value of additional emphasis on the water supply and water quality aspect of Corps planning stems in part from the Urban Studies Program now underway in the Corps, as well as from the need which many Corps districts and divisions now have for reappraisal of the uses of water stored in Corps reservoirs due to increased demand for municipal and industrial water (or other uses as recreation) not anticipated at the time the projects were planned and put into operation. Reapportionment of water stored in Corps reservoirs among uses and users will in many cases require investigations to determine the effect of physical changes on the reservoir and its operation and the economic and social impact on those who receive additional water and those who give up this resource, or receive water of a different quality or at a different time or place.

Other aspects of the water supply-quality planning which serve to direct IWR attention to this field are: (1) the potentialities for greater municipal-industrial integration of water supplies and water clean up; (2) the need for assessment of the impact of regionalization of water supply and quality management on efficiency of resource development plans; (3) appraisal of alternative management units (as metropolitan

areas, economic development districts, watersheds, river basins) in terms of methods for achieving the integration of separate supply and quality actions to each other and to other water development decisions; (4) broadened recognition of the range of water quality needs to include not only sewers and treatment plants, but silt, heat, exotic chemicals, storm runoff, oil spills and habitat improvement; (5) need to look past the emphasis on water quality regulation toward the planning of investments essential to supply and quality of the water resource and to the incentives which will encourage required investment in facilities expansion and intensive management; and (6) the objective of bringing water supply and quality fully into the comprehensive plans developed for water resources through joint federal-state efforts.

Each of these areas of interest serve to emphasize the desirability of considering water supply and quality needs in the context of all other water needs. IWR studies are designed to further this concept. The Institute studies reviewed here, see Table 1, have been carried out over a four-year period beginning in 1970. While each study was carried out by a different research team, the Institute staff has been responsible for the general design of each study and thus, for development of the links which run through this series of reports. The nature of these connecting links is a significant aspect of the Institute's program and of this position paper.

IWR REPORTS RELATING TO WATER SUPPLY AND QUALITY

Table 1

Publication Date	Title	Author(s)	Agency or Contractor and Address	Publication Series Identification Number
October 1970	The Role of the U.S. Army COE in Water Quality Management	Davis J. Allee, OSA Burnham H. Dodge, IWR	IWR Staff, Kingman Building, Fort Belvoir, Va 22060	71-1 IWR Research Report AD 734833
August 1971	Costs and Effects of a Water Quality Program for a Small Strip Mining Company	G. Richard Dreese Harold L. Bryant	Department of Economics, W. Va University, Morgantown, W. Va. 26505 Department of Economics & Finance, Xavier University, Cincinnati, Ohio 45207	71-7 IWR Record Report AD 740157
May 1972	A Methodology for Assessing Economic Risk of Water Supply Shortages	G. K. Young R. S. Taylor J. J. Hanks	Water Resources Engineers, Inc. Walnut Creek, California 94596	72-6 IWR Record Report AD 752153
July 1973	A Study of How Water Quality Factors Can Be Incorporated into Water Supply Analysis	William J. Leninger Julian M. Greene Frederick L. McCoy	Ernst & Ernst, 1225 Connecticut Ave, N.W., Washington, D.C. 20036	74-2 IWR Contract Report AD 782870 (3 Volumes bound in one)
February 1974	A Method for Integrating Surface and Ground Water Use in Humid Regions	Gert Aron Thomas Rachford Walter Stottman	Pennsylvania State University University Park, Pa 16802	74-3 IWR Contract Report AD 782873
July 1974	Interregional Planning of Water Resources Allocations by Systems Analysis Approach - A Summary Report	John E. Keith Jay C. Andersen Alton B. King Mark H. Andersen Thomas C. Andersen Calvin C. Clyde Daniel H. Hoggan	Utah Water Resources Research Laboratory, Utah State University, Logan, Utah 84322	74-4 IWR Contract Report AD 786698 Suppl 1 - AD A001075 Suppl 2 - AD A00822 Suppl 3 - AD A001076 Suppl 4 - AD A001077

<u>Publication Date</u>	<u>Title</u>	<u>Author(s)</u>	<u>Agency or Contractor and Address</u>	<u>Publication Series Identification Number</u>
October 1974	Changing Water Use in Selected Manufacturing Industries	Robert A. Leone J. Royce Ginn An-Loh Lin	National Bureau of Economic Research Madison Ave., New York, N. Y. 10016	74-10 IWR Contract Report AD A003264
December 1974	An Evaluation of Water Reuse for Municipal Supply	Daniel Dworkin Duane D. Baumann	Southern Illinois University Carbondale, Illinois 62901	74-11 IWR Contract Report AD A005053
December 1974	Evaluation of Quality Parameters in Water Resource Planning	Eric D. Bovet	Eric D. Bovet, Consultant 1112 Curtiss St, Alexandria, Va 22308	74-13 IWR Contract Report AD A005225
June 1975	Planning for Water Reuse - A Training Manual	Duane D. Baumann Daniel Dworkin	Holcomb Research Institute, Butler University, Indianapolis, Indiana 46208	Published for IWR
December 1975	Economic Concepts and Techniques Pertaining to Water Supply, Water Allocation and Water Quality	Eric D. Bovet	Eric D. Bovet, Consultant 1112 Curtiss St, Alexandria, Va 22308	IWR Paper 75-P5 AD A018242
August 1976	Development of a Regional Analysis for Water Supply and Water Quality Planning	Gert Aron Stephen Goelen and Others	Pennsylvania State University University Park, Pa 16802	Not completed

Background of Federal Interest and Legislation

IWR research in water supply and quality builds upon the federal interest and the long Corps of Engineers' involvement in these matters. Almost every session of Congress in the last 100 years has contemplated bills relating to water supply and quality factors. Concerning quality, the initial emphasis was on the regulatory aspect. The presence of refuse that might impede navigation was an early concern in New York Harbor (in 1886) but regulation of dumping was soon extended to other areas and broadened to include other aspects of water quality.

In summarizing for the Institute the gradual growth of federal interest in water quality, David J. Allee wrote:

Some technical assistance and planning were added as early as the 1920's and 1930's in support of a regulatory approach which was seen as solely a responsibility of local government. Human health was the emphasis and the virtual eradication of waterborne diseases played a major part in the nation's transition to an industrial state. [Note that now industrial processes are recognized as producing exotic byproducts with major health implications.] In 1948 and 1953 research and the development of treatment technology and more direct Federal participation in local regulation were authorized. In 1956, the Congress authorized grant-in-aid to municipalities (increased to significant size in 1970). Earlier, capacity in Federal reservoirs, largely built by the Corps, was authorized for low flow augmentation to meet water quality goals above the usual achievement level of treatment at the source of the wastes. With the authorization of stream flow regulation for water quality and particularly with the Water Resource Planning Act of 1965, comprehensive planning gave more detailed attention to water quality but to date, only reservoir capacity for water quality has been substantially influenced by such

planning. Planning has not been used to rationalize other forms of public investment for water quality to any significant degree, and has only made a modest contribution to enforcement.³

The evolution of public interest in water quality is highlighted by mention of some of the key studies by the government. The first major effort, a joint study by the Public Health Service and the Corps of Engineers, concerned development of a basin-wide water quality plan for the Ohio River. The report, "Ohio River Pollution Control (House Document 266, 78th Congress), is a landmark document. The planning process it outlined is for the most part still used. The essential steps involved: (1) knowledge about the sources and characteristics of pollution; (2) the determination of water uses; (3) establishing of quality criteria necessary to allow water uses to be achieved; (4) a remedial program for pollution control. This planning effort was viewed as an essential input to the basic regulatory process and federal overview by which water quality was and is to be achieved.

The 1948 Water Pollution Control Act (PL 80-845) provided for a planning process similar to that recommended by the Ohio River Pollution Control Report. Under this Act and the 1956 Amendment to it, the Public Health Service embarked upon a program of basin-wide

³Allee, David J. The Role of the US Army Corps of Engineers in Water Quality Management, Institute for Water Resources, US Army Corps of Engineers, IWR Report 71-7, Oct 1970.

comprehensive planning. These planning efforts were later linked through the Water Resources Council to the national, multi-purpose comprehensive planning of water and related land resources authorized by President Kennedy.

The Water Quality Act of 1965 expanded the concept of "comprehensive planning" in several ways: (1) It provided a general guide to the formulation of such programs by declaring that national policy was aimed at "...enhancing the quality and value of the nation's waters"; (2) it brought the states strongly into the water quality problem by requiring states to participate, stimulated by the knowledge that if they did not act, that the federal government would proceed to establish a water quality program; and (3) it contained the concept of a comprehensive program made up of approved state programs.

It proved difficult to carry out the intent of the 1965 water quality legislation. Allee found that:

According to the public statement of responsible officials, enforcement and grants for planning and construction have not been related in a program coordination sense. A review of the water quality plans show that they provide only a listing of the facilities for each existing jurisdiction that would not meet the ultimate standard. There is neither a sense of the relative timing of the investments that would be desirable, nor the relative cost and returns from alternative configurations of investment, control or standards of water quality. There is no thorough examination of the institutional arrangements to facilitate

particular objectives. Usually there is no explicit consideration of action measures other than domestic and industrial waste collection and treatment and low flow augmentation.^{4, 5}

In seeking to explain the isolation of most water quality planning from other aspects of water resources development during the period 1948-1966, Allee summarizes as follows:

The idea of formulating comprehensive plans has been included in water pollution control legislation since its initial modern formulation in the mid-1930's. At that time it was clearly in the minds of persons like Dr. Abel Wolman that comprehensive water pollution control plans would result in projects; that these projects should be tied together with other public works efforts relating to water resources; that a coordinated program would be placed before Congress with an annual budget; and that priorities would be established in order to take care of the most important pollution control needs.

Somewhere along the line we have either forgotten these early ideas or have preferred to move away from them. Our own estimate is that we have both forgotten and have found 'highway type allocations' more useful politically. For example, during the first eight years of the Water Pollution Control Act (1948-56) comprehensive planning was an important activity of the program. Yet Congress provided no funds to carry out the plans. From 1957 to 1965 Congress provided money to aid cities but new or updated comprehensive plans were not developed in any effective degree to guide the expenditure of these funds; and even if they had been developed, the Congress had made no provision for their use. By way of further example, Congress had neither established nor requested the Public Health Service to establish a procedure for

⁴Op. cit., p 2.

⁵Some regionalization of waste treatment was during this period started under special regional grants.

transmitting comprehensive plans for their information, review or use; the Act provided no procedure for Congress to grant its approval to a plan. The only provision to the Act that related comprehensive planning to the federal financing of municipal waste treatment work was the provision that projects be included in a comprehensive plan developed under the Act. In addition, the priority for project approval has been that provided each state based on its own set of projects (with little or no relationship to other projects on interstate waters). Local initiative usually must be relied upon to make a project available to all and most frequently the priority has been established on the basis of 'willingness or ability' of a city to proceed with the financing and construction of a waste treatment plant.^{6, 7}

The "Impending Crisis" of Water Supply and Quality

The word "crisis" has often been used in relation to water problems but after 1974 it became almost a standard prefix, applicable to both supply and to quality. The "water crisis" was compared to the "oil crisis." It was observed that the price of bottled water was higher than the top grades of gasoline! All of this was to a considerable degree the product of "journalism" and had little relation to real life water problems, but it was and is in a dramatic way a reminder that uncertainty and a feeling of insecurity is now widespread when it comes to the water resource.

There are many reasons for public concern with water. The efforts of the Environmental Protection Agency have highlighted the

⁶Op. cit. p 2.

⁷The Federal Water Quality Administration Report, "The Economics of Clean Water," Wash., D.C., Mar 1970 presents an analysis of regionalization, priority establishment and planning that generally parallels this analogy.

problem of quality in water and the great cost of attaining safe supply--a cost which may well preclude many water uses considered standard practice. Drought in parts of the nation has demonstrated that municipal and industrial supplies are only marginally adequate in many communities. The cost of water has gone up substantially in thousands of communities, and the taste at the tap is often strongly disinfectant in character. There are frequent discussions of water reuse and many people find that they have strong psychological objections to this, although they know it is happening and is inevitable for many communities.

Other reasons for concern relate to the pollution of groundwater by fertilizers and insecticides to the extent that it has damaged water supplies seriously in some areas. The fact that recreation such as swimming is not permitted in many streams due to dangerous levels of pollution has also had a disquieting effect.

There are also institutional and organizational problems that have caused widespread concern. Much of the nation outside the area of metropolitan and city water supply systems has been included in water supply districts of various types, organized under state and local laws. These districts have had in some cases US governmental financing through the U.S. Department of Agriculture, Farmer's Home Administration. But other financing is often available to them. In

general, they have rendered a valuable service to the farmers, villagers, rural industries, golf courses and airports which they serve. The improvement district type of organization has become an established way of obtaining the needed water supplies for large areas outside city or metropolitan systems. While there are many demonstrated advantages, there are some hazards to this method of organizing. The success of such systems depends upon an adequate source of water from which to pump into the pipelines.⁸ Thus, scaling of the system must be carefully carried out so that the system can deliver the water needed over its useful life. This requires estimates of the water that will be used when the system is built and over a substantial future period, say 20 years. In a great many cases this type of information has been lacking and even when it was available, it often showed that a larger system was needed than the initial users wished to invest in. This has led to many inadequately engineered systems from the point of view of sources of supply and of ability to deliver to customers the water they need. Often enough, by the time it is discovered that the community system is inadequate, the older sources of supply--springs, wells, mill ponds, or small reservoirs, ponds, or cisterns--have deteriorated, and

⁸Very rarely are special improvement districts sufficiently well financed to develop major sources of water supply. They frequently do tap ground water sources.

costly reconstructions are required. Such events have been commonplace, particularly in the mid-Continent where summer rainfall uses may vary greatly and serious drought is commonplace.

The water supply picture outside the large scale systems developed by cities is filled with uncertainty today. It is not a crisis, but it is a situation that needs careful study so that a higher degree of security in the water resource may be looked forward to. The water supply picture today is quite similar to that of land drainage in the 1920's and 1930's. Thousands of drainage districts were formed, often overlapping each other, all devoted to moving water off the adjacent cleared land. The problem was that they had no adequate outlets and the drainage districts lacked the jurisdictional or the financial ability to develop outlets. This resulted in hundreds of millions of dollars in losses through attempts to farm undrained land. Forfeiture of land for drainage taxes reached wholesale proportions and the states had to eventually take over most of the local drainage administration and some of the debt. Investors in drainage bonds usually lost most of their investment, the farmers their lands, and the state a major part of its tax base.

Communities today are not always able to develop adequate supplies. Pumping plants are being placed on streams where the supply is highly uncertain. Even a substantial river such as the

Kentucky has had so many water district pumping plants taking water from it that in a normal summer it shows signs of not being adequate. In a drought condition approaching that of the 1930's, there would not be sufficient flow to keep most of the water systems going. This is not an isolated case. Throughout the corn belt similar conditions exist. They are not uncommon in Ohio and Pennsylvania and in much of the South, in fact throughout the mid-continent.

Most state departments of natural resources are aware of the water supply problem. Many states have developed the practice of approaching the Corps of Engineers when reservoirs are being constructed and contracting for water supply storage up to the maximum the reservoir site will hold. Their purchases are far in excess of any clearly defined, immediate need for water. Indiana, North Carolina, Georgia and many other states have done this. Questioned about this practice, they have expressed only the general belief that the cost was modest to the state as the incremental cost of adding additional supply was low compared with any alternative way for obtaining water in this volume and quality. In a few instances the possibility of having to develop regional water supply systems to meet future needs for scarce supplies was expressed. In the words of one state official in Indiana, "We will need that water to fill up the tank trains to keep the southern part of the state going in a drought if we have one like 1930's." Ground-water is uncertain in most of southern Indiana and could not be relied

upon in many communities, even if they had retained standby pumping in their systems, which only a few have done.

Request for additional water supply for domestic and industrial use is the most common reason for the restudies which are now frequently required to reappportion water in Corps reservoirs to uses not included in the purposes for which the reservoirs were built. It is clear that in the years immediately ahead, a considerable number of such reappportionment studies will be required from Corps districts and divisions.⁹

These introductory observations on the water quality and the water supply problem emphasize the urgent need to look on these water problems as an integral part of the water resource planning process as a whole. This is not in any way to detract or diminish the importance of the local leaders in water quality and supply planning, but rather to emphasize that each community and each state must participate in the planning process. There will be no escape from the need to regionalize our water supply and our water quality management problems.¹⁰ The importance of standards and their enforcement are certain to intensify. The Environmental Protection Agency is deeply involved with local groups in this aspect of quality management. There must be an equal

⁹The Institute is now preparing a position paper dealing with the reappportionment problem.

¹⁰The Institute now has underway with Pennsylvania State College, a study of the economics of regional water systems.

involvement leading to the development of a sound regional base for supply management. It is primary in this way that the conditions that make for quality can be achieved. The water supply management and the water quality management planning process must come closer together. There can be no compromise between water quality and the enforcement procedures required for public safety. We must be sure that the water resource planning process as a whole (and supply and quality management must be truly brought into this process) has in it the flexibility for compromise and for bargaining.

In water supply and quality management, we face a situation where an era of intensive political bargaining is beginning. This should not surprise or offend anyone. Such bargaining is essential in our society to lay the political base for financial commitment between the federal executive and the congress on one hand and the local governmental units on the other. The basic object of this bargaining must surely be the creation of efficient regional administrative organizations for development of effective water supplies and efficient waste disposal plants and disposal plans, developed in full recognition of all other water resource development needs.

The Institute's studies in water supply and quality are prepared against this background of reorganized needs, with the belief that the experience of the Corps can be a valuable catalyst in achieving a restructuring of this vital part of the water resource planning establishment.

IN WATER SUPPLY AND QUALITY MANAGEMENT AN ERA OF INTENSIVE POLITICAL BARGAINING IS BEGINNING. SUCH BARGAINING IS ESSENTIAL IN OUR SOCIETY TO LAY THE BASES FOR FINANCIAL COMMITMENT BETWEEN THE FEDERAL EXECUTIVE AND THE CONGRESS ON THE ONE HAND, AND LOCAL, STATE AND REGIONAL AUTHORITIES ON THE OTHER.

The outcome of this bargaining cannot be completely foreseen, but the process is likely to lead the creation of regional administrative organizations for representing local and state interest in negotiations with the federal interest for development of effective water supply and water disposal plans and systems. The states are now preparing legislation under which regional organizations for water supply and quality management may be created.

THERE IS NEED FOR A PROCEDURAL METHODOLOGY FOR EXPLICITLY INCORPORATING QUALITY FACTORS INTO THE SUPPLY SIDE OF "WATER SUPPLY" ANALYSIS. WATER QUALITY AND WATER SUPPLY HAVE TOO OFTEN BEEN LOOKED ON AS SEPARATE WORLDS. HANDLED BY DIFFERENT AGENCIES, STUDIES BY SPECIALISTS OF DIFFERENT TRAINING, THE VITAL RELATIONSHIPS BETWEEN SUPPLY AND QUALITY ARE OFTEN OBSCURED IN WATER RESOURCE PLANNING.

IWR studies have shown that pragmatic methods for explicitly considering quality are scarce. For the most part, water supply studies assume that all water is of the same quality, or are content to mention that quality varies. Little is said of how it varies or to present this aspect quantitatively or to express what impact variations in quality might have on the supply problem.

The Institute has sought to develop a methodology which will make it possible to deal effectively with quality problems in studies of water supply. Quality should be defined in terms of the factors which might reduce quality, i. e., reduce the supply available for particular use. Such guides would enable Corps planners to give more adequate treatment to quality factors in water supply and to develop better plans consistent with options in resources.

There are many practical reasons for attempting a better integration of the functions of supply development and water quality enhancement. For example, without recognition of the supply-quality relationship, too many investment funds will be allocated to development of distant sources for water supplies with the disruption and dissipation of upland environments and the neglect of nearby waters which could be restored for less cost.

IN THE CORPS OF ENGINEERS PROGRAM, DROUGHT NEEDS JUST AS CAREFUL STUDY AS FLOOD. DROUGHT AND THE FEAR OF DROUGHT HAS PROBABLY SHAPED THE DEVELOPMENT OF AMERICA TO A GREATER DEGREE THAN FLOOD AND THE FEAR OF FLOOD. MUCH CAN BE LEARNED ABOUT THE VALUES PLACED ON THE USES OF WATER BY STUDYING THE RESPONSES DIFFERENT TYPES OF COMMUNITIES MAKE TO WATER SHORTAGE AND FEAR OF SHORTAGE. THIS RESPONSE HAS SHORT RUN AND LONG RUN ASPECTS; EACH PLAYS A SIGNIFICANTLY DIFFERENT ROLE IN RESOURCE DEVELOPMENT PLANNING.

Institute sponsored investigations have shown that procedures for estimating the frequency-drainage relationship resulting from a water shortage in urban areas can be developed and that both the short and long run responses of communities to drought, or fear of drought, are worth careful study.

THERE ARE MANY AREAS OF THE HUMID EASTERN UNITED STATES WHERE EXISTING SURFACE STORAGE RESERVOIRS CANNOT ANY LONGER ASSURE A RELIABLE WATER SUPPLY FOR THEIR SERVICE REGIONS WITHOUT INFRINGING ON COMPETING MULTI-PURPOSE STORAGE ALLOCATIONS. THIS FACT COUPLED WITH FREQUENT ENVIRONMENTAL AND ECONOMIC OBJECTIONS TO FURTHER RESERVOIR DEVELOPMENT ARGUE FOR MORE ATTENTION IN CORPS OF ENGINEERS PLANNING TO THE INTEGRATED USE¹ OF GROUND AND SURFACE WATER SOURCES.

The fact that water is relatively abundant, as in the humid eastern United States, does not necessarily assure a reliable water supply. Recent shortages are well documented. Risk of water shortage in humid regions is not dependent on the absolute quality of average annual rainfall but is more a function of hydrologic variability and the effective use of storage to dampen the consequence of variability. Ground water yield is generally less variable than surface water yield, but it is a more difficult source to develop and often cannot alone supply the total demand of the service region. Surface water supplies are increasingly difficult to develop for the reasons noted above.

Recognizing that procedures for developing and operating ground and surface water surplus together in an optimal manner have not been resolved, the Institute has denoted some of its resources to development of a method for integrating surface and ground water use in humid regions. The difficulties inherent in this task have been recognized by the American Water Works Association's Committee on Availability and Development of Water Supply, saying: "We do not know how to develop conjunctively both stream-flow and ground water for optimum use,"... They recommended that more research be undertaken in the field of joint utilization of ground and surface water. The "Principles and Standards" of the Water Resource Council also lend impetus to the study of joint use of ground and surface water sources, since the benefits and costs identified under the multi-objective accounts are likely to favor integrated ground and surface use. The methodologies developed in Institute studies were designed with the needs of Corps planners in mind, and they utilize examples and case studies where the problem of integrated use of ground and surface sources are outlined and their solution explained.

¹To avoid misleading terminology, the term "integrated use" in lieu of the more conventional "Conjunctive Use" is suggested for use in humid areas. Artificial recharge of ground water is essential for effective water conservation in arid regions and the term "conjunctive use" almost without exception, implies the presence of artificial recharge facilities that would not be considered recovery in the humid regions.

SYSTEMATIC INVESTIGATIONS OF WATER SUPPLY CAPACITY IS NEEDED TO COMBAT SERIOUS PROBLEMS OF SHORTAGE DUE TO DROUGHT AND TO HELP DIRECT CORPS OF ENGINEERS EFFORTS TO POINTS OF NEED. MANY PUMPING PLANTS AND ACCOMPANYING WATER DISTRIBUTION SYSTEMS ARE BEING BUILT WHERE WATER SOURCES ARE PROBABLY NOT ADEQUATE. THROUGHOUT THE MID-CONTINENT, PARTICULAR STREAMS MAY VARY GREATLY FROM LOW TO HIGH WATER.

A mid-continent water supply study has been discussed for several years in water resources circles. The Corps should take the lead in getting such an effort started, seeking the full cooperation of the states. A study of present withdrawals with a consumption estimate of future needs in present market areas would very likely highlight the magnitude of the supply problem in this part of the nation.

PURCHASE BY STATES AND OTHER LEGAL ENTITIES OF WATER SUPPLY STORAGE IN CORPS RESERVOIRS IN EXCESS OF CURRENT OR PORJECTED NEED IS NOW BEING OBSERVED OVER A WIDE AREA. THIS PRACTICE RESULTS IN RESERVOIRS BEING CONSIDERABLY LARGER THAN THEY WOULD OTHERWISE BE, FREQUENTLY SIZE IS LIMITED ONLY BY THE CHARACTER OF THE PHYSICAL SETTING. THIS PRACTICE AND ITS IMPACT NEEDS ANALYSIS FROM THE ECONOMIC, SOCIAL AND INSTITUTIONAL POINTS OF VIEW.

There are many reasons why the states or other entities enter into contracts for water supply in excess of apparent need. They may have only a general concept of potential future need and wish to be on the safe side. They may seek through purchase of storage to encourage the early development of projects desired primarily for other purposes. Water supply may also be looked on as an inducement for industrial location or other economic development. Extra supplies may be considered as an insurance against extreme drought or other hazard to water supplies. A careful study of the thinking which leads to such decisions should be beneficial to the Corps. It would reveal some of the forces which ultimately set the values on the water resources of the nation and on the Corps of Engineers program as it influences this aspect of water resource.

ANY ATTEMPT AT SIMPLIFYING, COMBINING OR AVERAGING WATER QUALITY PARAMETERS, OR AT JUDGING WATER QUALITY INDEPENDENTLY OF ITS INTENDED USES, IS FRAUGHT WITH HAZARDS.

The national approach to water resource planning needs to be modified to meet the challenges of water quality more effectively. This need is particularly critical at two levels: (1) the comprehensive regional and basin planning level, and (2) at the feasibility or "hardware" planning level.

Industrial waste represents about three times the volume of domestic waste presently collected - in terms of the oxygen-demand index. Yet the cost of collection and treatment appear to total about a third as much. Thus, from a national efficiency point of view a high priority should be given to industrial waste management. Increasing numbers of industries are joining in the municipal waste disposal systems. If this partnership is to work, emphasis must be placed on complete water quality analyses with a matching of individual parameter concentrations with the tolerances to each parameter in each water use. It is the most critical parameter that measures the highest value of water in any given use.

OUR NATIONAL APPROACH TO WATER RESOURCE PLANNING NEEDS TO BE MODIFIED TO MEET THE CHALLENGES OF WATER QUALITY MORE EFFECTIVELY. THE NEED FOR CHANGE CAN BE VIEWED AS CRITICAL AT TWO LEVELS - THE COMPREHENSIVE, REGIONAL AND BASIN PLANNING LEVEL AND AT THE FEASIBILITY OF "HARDWARE" PLANNING LEVEL.

The utopian basin authority capable of solving all problems will remain a myth. Federal planning, investment and regulatory authorities should therefore be directed toward encouraging fiscally viable water supply and waste collection and treatment for groups of communities and for whole metropolitan areas. This approach is institutionally practical and would solve a substantial part of the problem. The responsibility for achieving the integration of different functional interests such as water quality and quantity is clearly related to the need for balanced practicality of the means to correct pollution. Federal efforts to create the incentives needed for optimum and effective selection of water quality would further the objective of better integration of functions.

The full potential of various regional systems, such as metropolitan area water supply and waste disposal systems, will not be realized until they are made responsive to the interrelationships within the basins in which they fall. Thus, the regional concept becomes vital to the water resource planner.

THE REGIONALIZATION OF WATER SUPPLY SYSTEMS (AND TO A LESSER DEGREE WASTE MANAGEMENT SYSTEMS) WILL BECOME A NECESSITY FOR MOST OF THE U.S. WITHIN THE NEXT 25 YEARS. SUPPLY REGIONS ARE LIKELY TO GROW TO COVER BROAD GEOGRAPHIC PROVINCES, OFTEN COVERING TWO TO FIVE STATES AND PARTS OF STATE.

There are both advantages and disadvantages to regionalization of water systems. As the size of the jurisdiction increases, the emphasis on environmental control also increases. The incidence of degradation becomes more nearly internal to the decision-making unit since both the cause and effect are more likely to be within the jurisdiction. Under regional management, environmental control should thus become more competitive with other demands on local resources. Frequently regionalism leads to outstanding economies in investment. It also makes feasible the opportunities for higher level of operational skills.

Effective regionalism does not just happen. It requires strong institutional arrangement. The incentive to surmount local and state jurisdictional barriers must be great. The barriers must be surmounted for successful regionalization requires a commonality of investment decisions and a pooling of funds as it requires commitment and adherence to preplanned and priority-phased investment. It also requires complex cost-sharing arrangements in the interest of efficiency and equity. Where waste disposal and pollution management is a part of the collective purpose, industrial plant location at effluent discharge locations must also be planned with efficiency and equity in mind.

Many students of water supply and quality believe that it is in regionalization of the water supply and waste management problem that important aspects of the federal contribution lies. They believe that it is the federal government that has the ability to foster or create the kinds of institutions and financial arrangements that will permit state and local governments to overcome the inherent obstacles to regionalization and gain its benefits. It must also be realized that strong regional organizations may become forces which prove to have negative value for society in that they tend to become highly institutionalized and are difficult to divert or to alter.

THE FAILURE TO RELATE WATER SUPPLY AND ESPECIALLY WATER QUALITY TO OTHER WATER RESOURCE USES AND ACTIVITIES CONTINUES TO CREATE COST THAT SOCIETY SHOULD NOT HAVE TO BEAR.

While there have been many "comprehensive" surveys, several major attempts at systems analysis and development of a number of "models" of water supply and quality, there remains considerable evidence that the fragmentation of responsibility for water resources continues to lead to development of flood control, navigation, beach erosion, drainage and other water resource plans in which little attention is given to the fundamentals of water supply and water quality. In the field of agriculture, a similar situation quite often prevails. Cropping practices, fertilization schedules and insect control processes often have disastrous consequences to water supplies and water quality. This situation cannot be tolerated in good conscience. Too many water use activities affect or could affect water supply and quality for these elements to take second place in development planning.

The authority for Corps participation in comprehensive planning certainly includes supply and quality considerations for the water resources of the nation. The Corps also has authority to develop plans pertaining to water quality in a number of specific areas - San Francisco Bay, Southeast Michigan (Detroit Metropolitan area), south end of Lake Michigan (Chicago - Northern Indiana), Lake Erie and Lake Ontario, the Gulf Estuaries, Galveston Bay and the Chesapeake Bay. The North-eastern United States Water Supply Study offered the opportunity to develop plans for the integration of water supply and water quality programs.

It has been observed by Allee, Dodge and others that the Corps might contribute to the national needs for water supply and water quality in three ways: (1) through the development of regional plans for supply and treatment of water for quality, (2) through the coordination of regional interests and the management of systems providing regional impacts, and (3) in some instances, to supervise construction and operation of such facilities.

It is hoped that the participation in urban studies will bring to the Corps a better understanding of the overall supply quality program. It is clear that there will be major benefits from this experience, but the Corps may need to seek authority to incorporate water quality as an authorized purpose in all water resources plans. As Corps planning now stands, the quality problems still hold an "outside" position.

THERE IS NEED IN THE CORPS OF ENGINEERS AND IN COOPERATING AGENCIES FOR A STANDARDIZED PROCEDURE FOR ESTIMATING THE COST OF CONVENTIONAL WATER SUPPLIES.

There is a wealth of practical and professional experience with the development of water supplies from ground or surface sources in communities throughout the nation. Unfortunately this information is of greatly varying quality and is often in the hands of individuals and organizations who regard it as proprietary. As a consequence, individuals and communities have difficulty judging the merits of alternative approaches to water supply problems. Government planners frequently have not been in a much better position to prepare the cost estimates essential to evaluation.

A search has shown that there is not now available a published procedure or manual providing a standardized procedure for estimating costs of conventional water supplies, based on sound professional experience with representative water supply systems across the nation.

One important potential source for such information in a form useful to water resource planners was found. In 1963 Black and Veatch, consulting engineers of Kansas City, Missouri, under contract with the Office of Saline Water, U.S. Department of Interior, undertook to prepare a comprehensive report and a manual (outlining the steps for ready application of the estimating procedure) displaying a standardized procedure for the evaluation of fresh water sources throughout the central states. The manual was intended to be used by the Office of Saline Water in making preliminary comparison of the cost of conventional water supply with similarly established cost of saline water conversion in any particular location in the country. This work was used and proved of value, but it was not published. Only one or two copies of the reports covering this work now exist. Inquiry has developed the fact that this study by Black and Veatch was of exceptional quality and those familiar with it consider it of unique value. The Office of Saline Water, through its Director, Mr. John W. O'Meara, would have no objection to the Institute making use of, revising or updating, and publishing the Black and Veatch procedure for use by Corps planners and others.

The Institute has informally explored the possibility with Black and Veatch of updating the 1963 report. Fortunately the authors of this research are still in the company and expressed interest and willingness to update this work to make it fully responsive to current practices and needs in water supply planning.

In its original form, the main report provides in a comprehensive form the estimating methods and procedures shown in step form in the manual. The comprehensive report also provides a wealth of supporting data for each of the principal steps in the estimating procedures. This supporting data is provided for those who need more detailed information than is in the manual as to how cost and other relationships were determined.

The comprehensive report covers the following elements:

I. Required Information:

- A. Capacity of Future Facilities.
- B. Sources of Supply (impounded reservoirs, well supplies, intakes in natural lakes, rivers, streams).
- C. Future Nonreservoir Pipelines.
- D. Future Transmission Pipeline Pumping.
- E. Future Water Treatment.
- F. Future Treated Water Pumping.
- G. Land, Rights-of-Way, and Water Rights Cost.
- H. Required Information Form.

II. Capital Investment:

- A. Design Capacity of Future Facilities.
 - 1. Impounding reservoirs
 - 2. Well supplies
 - 3. Intake and pumping stations
 - 4. Transmission pipelines
 - 5. Transmission pipe pumping station
 - 6. Treatment plants
 - 7. Treated water pumping stations
 - 8. Summary of design capacity
- B. Construction Costs.
 - 1. Supply
 - 2. Transmission pipelines
 - 3. Pipeline pumping station
 - 4. Raw water storage

- 5. Water treatment plants and storage
- 6. Treated water pumping station

C. Trending of Construction Costs.

D. Engineering, Administration and Financial Costs.

E. Land, Rights-of-Way and Water Rights Cost.

- 1. Land
- 2. Rights-of-Way
- 3. Water rights

F. Interest During Construction.

G. Total Capital Investment.

H. Investment Per 1000 Gallons

III. Operation and Maintenance

A. General Costs.

- 1. Supply
- 2. Transmission pipeline
- 3. Raw water storage
- 4. Treatment
- 5. Disinfection
- 6. Pumping

B. Chemicals.

C. Pumping Power

D. Trending of Operation and Maintenance Costs.

E. Total Operation and Maintenance Costs.

F. Cost Per 1000 Gallons.

IV. Cost Determination Procedure

V. Example Application

The procedure provides data for estimating the cost of producing potable water from conventional supplies for system components of 100,000 gallons per day capacity to 100,000,000 gallons per day capacity.

When facilities exceeding 100,000,000 gallons per day capacity are indicated, further studies may be needed. In the absence of such studies, costs may be estimated in the procedures by increasing proportionally the values given for the 100,000,000 gallons per day facilities.

The updating of the comprehensive report and the manual is recommended as a step which would supply Corps planners with much valuable information. Through NTIS it would also be available to many communities, water districts and potential districts.

The updating would involve much more than a simple trend line estimate of cost increases since 1963. The original data was based on a careful review of actual water supply projects built in the U.S. between 1953 and 1963. An update would involve a study of the experiences from 1963 to 1974. In this period there have been many changes in practices which would make it necessary to modify the procedure to properly reflect current situations.

Black and Veatch, due to their extensive experience, were retained by the Office of Saline Water for a nationwide survey of desalination opportunities in 10,000 U.S. cities and towns based on formidable cost differentials with conventional water supplies. This and other governmental and private work has enabled them to develop one of the best files available on experience with water supply and water quality efforts in the U.S.

WATER RESOURCE PROJECTS ARE FREQUENTLY EVALUATED AS INDEPENDENT ENTITIES. WHERE THEY ARE PARTS OF A REGIONAL SYSTEM OR POTENTIAL REGIONAL SYSTEM, THEY SHOULD BE EVALUATED IN TERMS OF THIS SYSTEM AND THEIR CONTRIBUTION TO IT. THE DATA MAY NOT BE AVAILABLE IN SOME CASES TO DO THIS, BUT AS THE REGIONAL ASPECT IS DEVELOPED, THE APPROACH TO EVALUATION SHOULD RECOGNIZE THIS ASPECT AS BASIC TO EVALUATION OF INDIVIDUAL PROJECTS. REGIONAL SYSTEMS SHOULD BE EVALUATED IN TERMS OF REGIONAL REQUIREMENTS FOR WATER SUPPLIES OF SPECIFIED QUALITIES.

In the Northeastern Water Supply Study (NEWS) this aspect of project formulation and evaluation has been recognized, though not fully achieved.

IN THE WASTE WATER MANAGEMENT AND IN THE URBAN STUDIES PROGRAM THE CORPS IS ATTEMPTING TO COMBINE A NUMBER OF ELEMENTS -- FLOOD CONTROL, WATER SUPPLY, RECREATION, NAVIGATION, WATER QUALITY, ETC. -- IN SUCH A WAY THAT THE PACKAGE OF PROGRAMS CAPTURES ECONOMIC AND ENVIRONMENTAL BENEFITS THAT WOULD BE LOST IN SINGLE PURPOSE PLANNING. THIS IS A DESIRABLE GOAL BUT IT HAS SOME HAZARDS -- THE VITAL ELEMENTS MAY BE LOST OR DIMINISHED. ALL PLANS WHICH HAVE MULTIPLE PURPOSES MUST BE CARRIED OUT WITH A CLEAR UNDERSTANDING OF THE PARAMOUNT NEED. THIS FACT IS BEING OVERLOOKED IN MANY CORPS OF ENGINEERS PLANNING EFFORTS. IT IS OFTEN NECESSARY TO GIVE UP MUCH THAT IS VALUABLE AND DESIRED TO OBTAIN THAT WHICH IS INDISPENSABLE.

In working with local interest, the federal planner has a responsibility to make clear the federal interest. The local interests have the responsibility to make clear their wishes and needs. Only when this is done can plans responsive to both of these be developed. The trade off of federal interest for local interests should not be done without explicit understanding of why it is done. This understanding will involve legal, economic and social considerations.

THE FEDERAL WATER POLLUTION CONTROL ACT WILL SERVE AS A GREAT STIMULUS TO THE REGIONALIZATION OF WATER SUPPLY AND WASTEWATER MANAGEMENT SYSTEMS, AS IT REQUIRES REGIONAL PLANNING FOR REGIONAL SYSTEMS IMPLEMENTED BY REGIONAL AGENCIES TO THE FULLEST POSSIBLE EXTENT. THE REGIONAL APPROACH IS CONSIDERED AN IMPORTANT STEP TOWARD REDUCING CAPITAL AND OPERATING COST OF WASTE TREATMENT SYSTEMS. THIS EMPHASIS ON REGIONALISM WILL NOT BEAR FRUIT WITHOUT A CLEARER CONCEPT THAN NOW EXISTS OF WHAT REGIONALISM IMPLIES.

The objectives set forth for water supply and quality management require the evaluation of water supply and waste water management alternatives on a regional basis. It is not clear, however, what type of regionalism is most suitable to the water supply and waste management problem. The economic region may in this case be more important than the traditional physiographic region. Doubtless the political boundaries are important, particularly where financial problems are involved. A combination of elements will doubtless define the boundaries and the working of regional approaches. On a lower level of consideration are such questions as: (1) How to determine the area which public water systems can effectively be extended to serve? (2) When is it efficient to join water systems and which are the deciding elements in such consolidation plans? (3) How should regional water sources be allocated to meet regional requirements?

The great weakness of present water and waste disposal systems is that they leave large areas unserved. If well designed regional systems can overcome this limitation, they will become a vital element in water resource plans of the future.

THE REGIONALIZATION OF WATER SYSTEMS AND WASTE DISPOSAL SYSTEMS RAISES MANY INSTITUTIONAL QUESTIONS WHICH ARE IMPORTANT TO CORPS PLANNING. THESE ARE THE SUBJECT OF A SEPARATE STUDY IN IWR WHICH WILL TAKE THE FORM OF A PLANNING MANUAL. EMPHASIS WILL BE GIVEN TO THE NATURE AND PURPOSE OF INSTITUTIONAL ANALYSIS IN THE URBAN STUDIES PLANNING PROCESS; TO THE REQUIREMENTS FOR ORGANIZATIONAL AND FINANCIAL ANALYSIS IN URBAN STUDIES; AND TO THE INSTITUTIONAL IMPLICATIONS OF REGIONALIZATION AND THE REQUIREMENTS OF SYSTEMS ANALYSIS.

There are always stresses between national and local governments. The institutions which are created to support water resource needs should be of the types which encourage dialogue and set the stage for cooperative planning in which each side can make its views known. A conflict situation is developing between federal viewpoints and positions and state and local viewpoints. Water supply and water quality planning are issues about which federal-state conflicts are developing. A clear definition of the federal interest would help to lower tensions.

THE BARRIERS MUST BE SURMOUNTED FOR SUCCESSFUL REGIONALIZATION REQUIRES A COMMONALITY OF INVESTMENT DECISIONS AND A POOLING OF FUNDS AS IT REQUIRES COMMITMENT AND ADHERENCE TO PREPLANNED AND PRIORITY-PHASED INVESTMENT. IT ALSO REQUIRES COMPLEX COST-SHARING ARRANGEMENTS IN THE INTEREST OF EFFICIENCY AND EQUITY. WHERE WASTE DISPOSAL AND POLLUTION MANAGEMENT IS A PART OF THE COLLECTIVE PURPOSE, INDUSTRIAL PLANT LOCATION AT EFFLUENT DISCHARGE LOCATIONS MUST ALSO BE PLANNED WITH EFFICIENCY AND EQUITY IN MIND.

Many students of water supply and quality believe that it is in regionalization of the water supply and waste management problem that important aspects of the federal contribution lies. They believe that it is the federal government that has the ability to foster or create the kinds of institutions and financial arrangements that will permit state and local governments to overcome the inherent obstacles to regionalization and gain its benefits. It must also be realized that strong regional organizations may become forces which prove to have negative value for society in that they tend to become highly institutionalized and are difficult to divert or to alter.

APPENDIX A

- A-1 Ackoff, Russel L. and Sasieni, Maurice W., Fundamentals of Operation Research, 1968, John Wiley & Sons, Inc., New York.
- A-2 Acres, H. G., Ltd, Water Quality Management Methodology and its Application to the Saint John River (Appendix H), p. 76, August 1971.
- A-3 Ad Hoc Water Resources Council, Policies, Standards and Procedures in the Formulation, Evaluation and Review of Plans for Use and Development of Water and Related Land Resources, Supplement No. 1, Evaluation Standard for Primary Outdoor Recreation, Wash, D.C., 1964.
- A-4 Alchian, Armen A., "Costs and Outputs," Readings in Microeconomics edited by William Breir and Harold M. Hochman, pp. 159-171, 1971, Holt, Rinehart and Winston, Inc., New York.
- A-5 Allen, R.D.G., Mathematical Analysis for Economists, 1938, New York, N.Y., St. Martin's Press, Inc.
- A-5a Alvord, Burdick & Howson, Engineers, Chicago, Illinois, 1967, Report on Water Supply Requirements, The York Water Company, York, Pennsylvania.
- A-6 American Public Health Association, Standard Methods for the Examination of Water and Wastewater, 13th edition, 4th printing, p. 769, 1973.
- A-7 American Water Works Association, Inc., Water Quality and Treatment, 3d edition, New York, N.Y., 1971: McGraw-Hill Book Co.
- A-8 American Water Works Association Committee on Availability and Development of Water Supply, "Research Needed on Availability and Development of Water Supply," Journal American Water Works Association, Vol. 61, No. 4, pp. 159-162, April 1969.
- A-9 Amin, P.M. and S.V. Canapati, "Biochemical Changes in Oxidation Ponds," Journal, Water Pollution Control Federation, Vol. 44, No. 2, p. 183-200, February 1972.
- A-10 Amir, R., Optimum Operation of Multi-Reservoir Water Supply System, p. 192, 1967, Department of Engineering - Economic Planning, Standford University, Palo Alto, California.
- A-11 Andersen, Jay C., Hiskey, Harold H., and Lackawathana, Suwaphot, "Application of Statistical Decision Theory to Water Use Analysis in Sevier County, Utah," Water Resources Research, Vol. 7, No. 3, pp. 443-452, June 1971.
- A-12 Anderson, Mark H., An Economic Analysis of Supply and Demand for Irrigation Water in Utah: A Linear Programming Approach, Forthcoming in 1973, M.S. Thesis, Utah State University, Logan, Utah.

- A-13 Anderson, N.E., and B. Sosewitz, "Chicago Industrial Waste Surcharge Ordinance," Journal, Water Pollution Control Federation, Vol. 43, No. 8, pp. 1591-99, August 1971.
- A-14 Anderson, M.H., J.C. Andersen, J.E. Keith, and C.G. Clyde, The Demand for Irrigation Water in Utah, Forthcoming PRWG100-4, Utah Water Research Laboratory, Logan, Utah.
- A-15 Anderson, P.W. and McCall, J.E., Effects of Drought on Stream Quality in New Jersey. ASCE Proc. 94 [SA5 No. 6138]. Bibliography, Maps. 779-88 0 68.
- A-16 Andersen, P.W., et al., "Impact of Drought on New Jersey's Water Resources," Journal of the Irrigation and Drainage Division, ASCE, Vol. 98, No. IR 3, pp. 375-385, September 1972.
- A-17 Anderson, Thomas C., Water Resources Planning to Satisfy Growing Demand in an Urbanizing Agricultural Region, p. 22, 1972, PRWG100-1, Utah Water Research Laboratory, College of Engineering, Utah State University, Logan, Utah.
- A-18 Angino, E.E., L.M. Magnuson, and G.F. Stewart, "Effects of Urbanization on Storm Water Runoff Quality: A Limited Experiment at Naismith Ditch, Lawrence, Kansas," Water Resources Research, Vol. 8, No. 1, pp. 135-140, February 1972.
- A-19 Anonymous, "Agriculture Poses Waste Problems," Environmental Science and Technology, Vol. 4, No. 12, pp. 1098-1100, December 1970.
- A-20 Anonymous, "Canals Offer Vast Cooling Potential," Environmental Science and Technology, Vol. 4, No. 4, p. 287, April 1970.
- A-21 Anonymous, "Cities Treat Industrial Process Wastes," Environmental Science and Technology, Vol. 5, No. 10, pp. 1000-02, October 1971.
- A-22 Anonymous, "Cleveland Opts for Physical-Chemical," Environmental Science and Technology, Vol. 6, No. 9, pp. 732-784, September 1972.
- A-23 Anonymous, "Desalters Eye Industrial Markets," Environmental Science and Technology, Vol. 4, No. 8, p. 634, August 1970.
- A-24 Anonymous, "Drinking Water: Is It Drinkable," Environmental Science and Technology, Vol. 4, No. 10, pp. 811-13, October 1970.
- A-25 Anonymous, "Effluent Guidelines are on the Way," Environmental Science and Technology, Vol. 6, No. 9, pp. 786-87, September 1972.
- A-26 Anonymous, "The Great Phosphorus Controversy," Environmental Science and Technology, Vol. 4, No. 9, pp. 725-26, September 1970.
- A-27 Anonymous Editorial, "Land Disposal of Wastewater," Journal, Water Pollution Control Federation, Vol. 44, No. 5, p. 900, May 1972.

- A-28 Anonymous, "Manging Regional Water Treatment Systems," Environmental Science and Technology, Vol. 6, No. 5, pp. 402-03, May 1972.
- A-29 Anonymous, "Quality Goals for Potable Water -- Statement of Policy," Journal, AWWA, Vol. 60, No. 12, pp. 1317-22, December 1968.
- A-30 Anonymous, "Raw Water Quality Criteria for Public Supplies," Journal, AWWA, Vol. 61, No. 3, pp. 133-38, March 1969.
- A-31 Anonymous, "Reclaiming Industrial Waste Water," Environmental Science and Technology, Vol. 5, No. 4, pp. 306-07, April 1971.
- A-32 Anonymous, "Recycling Sewage Biologically," Environmental Science and Technology, Vol. 5, No. 2, pp. 112-13, February 1971.
- A-33 Anonymous, "Recycling Sludge and Sewage Effluent by Land Disposal," Environmental Science and Technology, Vol. 6, No. 10, pp. 871-73, October 1972.
- A-34 Anonymous, "Sludge Handling: The Hardest Phase of Waste Treatment," Environmental Science and Technology, Vol. 5, No. 8, pp. 670-71, August 1971.
- A-35 Anonymous, "Thermal Pollution in Uncharted Waters," Environmental Science and Technology, Vol. 5, No. 12, pp. 1170-72, December 1971.
- A-36 Aron, G., "Optimization of Conjunctively Managed Surface and Ground Water Resources by Dynamic Programming," Water Resources Center Contribution No. 129, June 1969, University of California.
- A-37 Aron, G., Rachford, T.M., and Reich, B.M., "Optimization of Water Resources Allocations by Operational Techniques," presented at Convention: Water for the Future, 1970, Republic of South Africa.
- A-38 Azad, H.S., and J.A. Borchardt, "Variations in Phosphorus Uptake by Algae," Environmental Science and Technology, Vol. 4, No. 9, pp. 737-43, September 1970.
- B-1 Babbitt, Harold E., "Water Supply and Treatment," Civil Engineering Handbook, edited by Leonard C. Urquhart, pp. 10.2-10.5, 1959, McGraw-Hill Book Co., New York.
- B-2 Babbitt, Harold E., and E. Lind, James J., Water Supply Engineering, 1955, McGraw-Hill Book Co., New York.
- B-3 Bagley, Jay M., et al., Developing a State Water Plan: Utah's Water Resources -- Problems and Needs, A Challenge, 1963, Utah State University and Utah Water and Power Board, Salt Lake City, Utah.

- B-4 Bain, Joe S., Richard E. Caves, and Julius Margolis, Northern California's Water Industry: The Comparative Efficiency of Public Enterprise in Developing a Scarce Natural Resource, 1966, The John Hopkins Press, Baltimore, Maryland.
- B-5 Baldwin, R.A., A Model of Optimum Water Allocation under Iowa's Permit System, p. 147, 1970, M.S. thesis, Iowa State University, Ames, Iowa.
- B-6 Ballinger, D.G., "Instruments for Water Quality Monitoring," Environmental Science and Technology, Vol. 6, No. 2, pp. 130-33, February 1972.
- B-7 Banks, H.O., "Utilization of Underground Storage Reservoirs," Transactions, ASCE, Vol. 118, pp. 220-34, 1953.
- B-8 Barish, Norman N., Economic Analysis, 1962, McGraw-Hill Book Co., New York.
- B-9 Barksdale, Henry C., Effects of the Drought on Water Resources--Surface and Subsurface Hydrology, January 1971.
- B-10 Baumann, D.D., "Perception and Public Policy in the Recreational Use of Domestic Water Supply Reservoirs," Water Resources Research, Vol. 5, No. 3, pp. 543-54, June 1969.
- B-11 Baumol, William J., Economic Theory and Operations Analysis, 1965, 2nd Edition, Englewood Cliffs, N.J.: Prentice-Hall, Inc.
- B-12 Baumol, W.J., Economic Theory and Operations Analysis, 1972, 2nd Edition, Englewood Cliffs, N.J.: Prentice-Hall, Inc.
- B-13 Baumol, W.J., and W.E. Oates, "The Use of Standards and Prices for Protection of the Environment," Swedish Journal of Economics, Vol. 73, No. 1, pp. 42-54, March 1971.
- B-14 Baumol, W.J., Welfare Economics and the Theory of the State, 2nd Edition, 1965, G. Bell & Sons, London.
- B-14a Bayer, M.B., "A Non-Linear Mathematical Programming Model for Water Quality Management," Proceedings, International Symposium on Modeling Techniques in Water Resources Systems, Vol. 2, pp. 341-51, May 1972.
- B-15 Bean, E.L., "Evolution of Water Quality Goals," Journal, AWWA, Vol. 61, No. 7, pp. 317-20, July 1969.
- B-16 Beard, L.R., "Estimating Long-Term Storage Requirements and Firm Yields of Rivers," General Assembly at Berkeley of International Union on Geodesy and Geophysics, pp. 151-66, 1964.
- B-17 Beard, L.R., and Kubik, H.E., "Drought Severity and Water Supply Dependability," Journal of the Irrigation and Drainage Division, ASCE, Vol. 98, No. 1R 3, pp. 433-42, September 1972.

- B-18 Beighter, O.S., R.M. Crisp, and W.L. Meier, "Optimization by Geometric Programming," Journal of Industrial Engineering, Vol. 19(3), pp. 117-20.
- B-19 Bella, D.A., "Dissolved Oxygen Variations in Stratified Lakes," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 96, No. SA5, pp. 1129-46, October 1970.
- B-20 Bellinger, E.G., "Eutrophication in Relation to Water Supplies," Journal, Society for Water Treatment and Examination, Vol. 19, Part 4, pp. 400-09, 1970.
- B-21 Bendixen, T.W., et al., "Ridge and Furrow Liquid Waste Disposal in a Northern Latitude," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 94, No. 1, pp. 147-57, February 1968.
- B-22 Benjamin, Jack R. and Cornell, C. Allin, Probability, Statistics and Decision for Civil Engineers, 1970, McGraw-Hill Book Co., New York.
- B-23 Berg, G., "Integrated Approach to the Problem of Viruses in Water," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 97, No. SA 6, pp. 867-82, December 1971.
- B-25 Berthouex, Paul M. and Polkowski, Lawrence B., "Design Capacities to Accommodate Forecast Uncertainties," Journal of the Sanitary Engineering Div., ASCE, Vol. 96, No. SA 5, pp. 1183-1210, October 1970.
- B-26 Bishop, A.B., and D.W. Hendricks, "Water Reuse Systems Analysis," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 97, No. 1, pp. 41-57, February 1971.
- B-27 Black, Theres R., Jewell J. Rasmussen, and Frank C. Hachman, Population Projections; Utah and Utah's Counties, 1967, Economic and Population Studies, Utah State Planning Program, Salt Lake City, Utah.
- B-28 Black & Veatch, Economic Effects of Mineral Content in Municipal Water Supplies, U.S. Office of Saline Water R&D Progress Report No. 260, May 1967.
- B-29 Black & Veatch, Standardized Procedure for Estimating Costs of Conventional Water Supplies, prepared for the U.S. Office of Saline Water, 87 pages, 1963.
- B-30 Blumenstock, George, Jr., Drought in the U.S. Analyzed by Means of the Theory of Probability, 1942, U.S. Department of Agriculture.

- B-31 Board of Directors, Metropolitan Washington Council of Governments, Resolution Adopting Plan of Action for Conservation of Water Use During Periods of Low Flows in the Potomac River, July 10, 1969.
- B-32 Bohan, J.P., and J.L. Grace, Jr., Mechanics of Flow from Stratified Reservoirs in the Interest of Water Quality: Hydraulic Laboratory Investigation, July 1969, Army Engineer Waterways Experiment Station.
- B-33 Bortleson, G.C., and G.F. Lee, "Recent Sedimentary History of Lake Mendota, Wisconsin," Environmental Science and Technology, Vol. 6, No. 9, pp. 799-808, June 1972.
- B-34 Boswell, A.M., "Industrial Wastes as a Source of Tastes and Odors in Water Supplies," Biology of Water Pollution, pp. 244-246, 1967, FWPCA.
- B-35 Bourodimos, E.L., "Turbulent Transfer and Mixing of Submerged Heated Water Jet," Water Resources Research, Vol. 8, No. 4, pp. 982-997, August 1972.
- B-36 Bourquard, Geil and Associates, Consulting Engineers, Harrisburg, Pennsylvania, Report on Water Resources Study of Codorus Creek Basin and Vicinity, June 1962.
- B-37 Bovet, E.D., "Industrial Waste Desalting for Byproduct Recovery," Journal, American Water Works Association, Vol. 62, No. 9, pp. 539-542, September 1970.
- B-38 Bovet, Eric D., Consulting Economist, Alexandria, Virginia, Scope of Conceptualization for Water Shortage Study, April 1971.
- B-39 Boyd, J.H., Pollution Charges "Income and the Cost of Water Quality Management," Water Resources Research, Vol. 7, No. 4, pp. 759-769, August 1971.
- B-40 Boyd, J.H., Pollution Charges, Waste-Assimilative Capacity Investment, and Water Quality: The Public Costs of a Public Good, OWRR Project No. A-010 - OHIO, p. 89, January 1969.
- B-41 Bramer, H.C., "Pollution Control in the Steel Industry," Environmental Science and Technology, Vol. 5, No. 10, pp. 1004-1008, October 1971.
- B-42 Brandt, G.H., et al., An Economic Analysis of Erosion and Sediment Control for Watersheds Undergoing Urbanization, p. 181, 1972.
- B-43 Brant, Russell A., "Geological Description and Effects of Strip Mining on Coal Overburden Material," The Ohio Journal of Science, pp. 68-75, March 1964.
- B-44 Brill, E.D., Economic Efficiency and Equity in Water Quality Management, 1972, Ph.D. Thesis, The Johns Hopkins University, Baltimore, Md.

- B-45 Brock, Samuel and David B. Brooks, The Myles Job Mine, 1966, Office of Research and Development, West Virginia University.
- B-46 Brooks, David B., "Analysis: Surface Mine Regulation," Coal Mining and Processing, March 1970.
- B-47 Brooks, David B., "Strip Mine Reclamation and Economic Analysis," Natural Resources Journal, pp. 13-44, January 1966.
- B-48 Brooks, K.N., and D.B. Thorud, "Antitranspirant Effects on the Transpiration and Physiology of Tamarisk," Water Resources Research, Vol. 7, No. 3, pp. 499-510, June 1971.
- B-49 Brown, G.W., and J.T. Krygier, "Clear-Cut Logging and Sediment Production in the Oregon Coast Range," Water Resources Research, Vol. 7, No. 5, pp. 1189-1198, October 1971.
- B-50 Brown, G., Jr., and B. Mar, "Dynamic Economic Efficiency of Water Quality Standards or Charges," Water Resources Research, Vol. 4, No. 6, pp. 1153-1159, December 1968.
- B-51 Brown, R., et al, "A Water Quality Index-- Crashing the Psychological Barrier," December 1971, a paper presented at the annual meeting of the American Association for the Advancement of Science. Also unpublished paper presented by Brown, February 1, 1973, at the Annual Meeting of ASCE in Washington, D.C., title: "Validating Water Quality Index."
- B-52 Brown, R., McClelland, N., DeFninger, R., and O'Connor, M., "A Water Quality Index-Crashing the Psychological Barrier," a paper presented at the December 28, 1971 meeting of the American Association for the Advancement of Science in Philadelphia, Pennsylvania.
- B-53 Brown, R., "A Water Quality Index-Do We Dare?," Water & Sewage Works, Vol. 117, No. 10, pp. 339-343, October 1970.
- B-54 Bruvold, W.H., and P.C. Ward, "Using Reclaimed Wastewater -- Public Opinion," Journal, Water Pollution Control Federation, Vol. 44, No. 9, pp. 1690-1696, September 1972.
- B-55 Buchan, S., "Integrating Ground and Surface Water Usage," Engineer, Vol. 214, No. 57, pp. 846-847, November 1962.
- B-56 Buras, N., and Hall, W.A., "An Analysis of Reservoir Capacity Requirements for Conjunctive Use of Surface and Ground Water Storage," International Association of Scientific Hydrology, Pub. No. 57, pp. 556-563, 1961.
- B-57 Buras, N., "Conjunctive Operation of Dams and Aquifers," Journal of the Hydraulics Division, ASCE, Vol. 89, No. HY6, pp. 111-131, November 1963.

- B-58 Buross, N., "Conjunctive Operation of a Surface Reservoir and a Ground Water Aquifer," International Association of Scientific Hydrology, Pub. No. 63, pp. 492-501, 1963.
- B-59 Buross, N., "Dynamic Programming in Water Resources Development," Advances in Hydrosience, edited by V.T. Chow, Vol. 3, 1966, Academic Press, New York.
- B-60 Buross, N., "Systems Engineering and Aquifer Management," International Association of Scientific Hydrology, Pub. No. 72, pp. 466-473, 1965.
- B-61 Buross, N., "A Three-Dimensional Optimization Problem in Water Resources Engineering," Operations Research Quarterly, Vol. 16(4), pp. 419-427, 1965.
- B-62 Bureau of Statistics, Harrisburg, Pennsylvania, 1968 Industrial Directory of the Commonwealth of Pennsylvania-18th Edition, 1969.
- B-63 Burt, O.R., "The Economics of Conjunctive Use of Ground and Surface Water," Hilgardia, Vol. 36, No. 2, pp. 31-111, December 1964.
- B-64 Burt, O.R., "Optimal Resources Use Over Time With an Application to Ground Water," Management Science, Vol. 11(1), pp. 80-91, 1964.
- B-65 Busch, A.W., "A Five-Minute Solution for Stream Assimilative Capacity," Journal, Water Pollution Control Federation, Vol. 44, No. 7, pp. 1453-1456, July 1972.
- B-66 Butcher, W.S., "Mathematical Models for Optimizing the Allocation of Stored Water," International Association of Scientific Hydrology, No. 81, pp. 714-723, 1968.
- C-1 Cairns, J., Jr., and K.L. Dickson, "A Simple Method for the Biological Assessment of the Effects of Waste Discharges on Aquatic Bottom-Dwelling Organisms," Journal, Water Pollution Control Federation, Vol. 43, No. 5, pp. 755-772, May 1971.
- C-2 California Water Resources Department, "Planned Utilization of Ground Water Basins: Coastal Plain of Los Angeles County, Appendix C - Operation and Economics," Bulletin No. 104, December 1966, State of California, Sacramento, California.
- C-3 Camp, T.R., Water and Its Impurities, 1963, Reinhold Book Corp., New York, N.Y.
- C-4 Camp, Thomas R., and Lawler, Joseph C., "Water Supplies," Handbook of Applied Hydraulics, edited by Calvin Victor Davis and Kenneth E. Sorensen, pp. 37.51-37.58, 1969, McGraw-Hill Book Co., New York.
- C-5 Campbell, E.W., "Methemoglobinemia -- A Problem," Journal, Maine Medical Association, January 1960.

- C-6 Cannon, D.W., "Industrial Reuse of Water: An Opportunity for the West," Water and Sewage Works, Vol. 111, No. 5, pp. 250-254, May 1964.
- C-7 Canter, L.W., and A.J. Englands, Jr., "States Design Criteria for Stabilization Ponds," Journal, Water Pollution Control Federation, Vol. 42, No. 10, pp. 1840-1847, October 1970.
- C-8 Cantrell, R.P., et al., "A Technical and Economic Feasibility Study of the Use of Municipal Sewage Effluent for Irrigation," Symposium on Municipal Sewage Effluent for Irrigation, pp. 135-156, July 1968, Louisiana Polytechnic Institute, Ruston, La.
- C-9 Carr, Charles, R., and Howe, Charles W., Quantitative Decision Procedures In Management and Economics, 1964, McGraw-Hill Book Co., New York.
- C-10 Carswell, J.H., J.N. Symons, and G.G. Robeck, "Research on Recreational Use of Watersheds and Reservoirs," Journal, AWWA, Vol. 61, No. 6, pp. 297-304, June 1969.
- C-11 Carter, B.J., J.P. Haney, and E.E. Pyatt, "Valuation of Flow Augmentation Releases," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 97, No. 3, pp. 345-359, June 1971.
- C-12 Cole, C.A., and E.J. Genetelli, "Decarbonation and Deaeration of Water by Use of Selective Hollow Fibers," Environmental Science and Technology, Vol. 4, No. 6, pp. 514-517, June 1970.
- C-13 Cederstrom, D.J., Baker, John A., and Tarver, George R., "Ground Water in the North Atlantic Region," Appendix D of North Atlantic Regional Water Resources Study prepared by the U.S. Geological Survey in cooperation with the U.S. Army Corps of Engineers, New York, 1971.
- C-14 Chen, C.W., and R.E. Selleck, "A Kinetic Model of Fish Toxicity Threshold," Journal, Water Pollution Control Federation, Vol. 41, No. 8, pp. 294-303, August 1969.
- C-15 Chiang, Alpha C., Fundamental Methods of Mathematical Economics, 1967, McGraw-Hill Book Co., New York, N.Y.
- C-16 Chilton, C.H., "Six-Tenths Factor Applies to Complete Plant Costs," Cost Engineering in the Process Industries, 1960, McGraw-Hill Book Co., Inc., New York.
- C-17 Chow, Ven Te, ed., Handbook of Applied Hydrology, 1964, McGraw-Hill Book Co., New York.
- C-18 Christensen, Rondo A., Lynn H. Davis, and Stuart H. Richards, "Enterprise Budgets for Farm and Ranch Planning in Utah," Research Reports 5, 1972, Utah State University, Logan, Utah.

- C-19 Christensen, R.A., and S.H. Richards, "Price Trends for Decision Making in Agriculture," Utah Resources Series 49, p. 83, 1969, Utah Agricultural Experiment Station, Logan, Utah.
- C-20 Chun, R.R.D., Mitchell, L.R., and Mide, K.W., "Ground Water Management for the Nation's Future - Optimum Conjunctive Operation of Ground Water Basins," Journal of the Hydraulics Division, ASCE, Vol. 90, No. HY4, pp. 79-95, July 1964.
- C-21 Cicchetti, C.J., et al., "Recreation Benefit Estimation and Forecasting: Implications of the Identification Problem," Water Resources Research, Vol. 8, No. 4, pp. 840-850, August 1972.
- C-22 Clark, John W., and Viessman, Warren, Jr., Water Supply and Pollution Control, 1965, International Textbook Company, Scranton, Pennsylvania.
- C-23 Clark, J., Viessman, W., and Hammer, J., Water Supply and Pollution Control, 2nd Ed., 1971, International Textbook Co., Scranton, Pennsylvania.
- C-24 Clausen, G.S., "Optimal Operation of Water Supply Systems," Technical Reports on Hydrology and Water Resources, June 1970, The University of Arizona, Tucson, Arizona.
- C-25 Clawson, M., and J.L. Knetsch, Economics of Outdoor Recreation, 1966, John Hopkins University Press, Baltimore, Md.
- C-26 Cleary, Edward J., "Water Quality Management," Water Pollution Control Federation Journal, February 1970.
- C-27 Close, E.R., Beard, L.R., and Dawdy, D.R., "Objective Determination of Safety Factor in Reservoir Design," Journal of the Hydraulics Division, ASCE, Vol. 96, No. ST5, pp. 1167-1177, May 1970.
- C-28 Cluff, A.T., "The Role of the Federal Government in the Industrial Expansion of Utah During World War II," Unpublished Master's thesis, p. 193, 1964, Utah State University Library, Logan, Utah.
- C-29 Clyde, C.G., A.B. King, and J.C. Andersen, Application of Operations Research Techniques for Allocating Colorado River Water in Utah, PRWG73-2, p. 132, 1971, Utah Water Research Laboratory, Utah State University, Logan, Utah.
- C-30 Coffey, P.J., and L. Ortolano, "Economic Framework for Salinity Control Projects," Journal, American Water Works Association, Vol. 61, No. 5, pp. 237-241, May 1969.
- C-31 Cohen, Philip, Franke, O.L., and McClymonds, N.E., Hydrologic Effects of the 1962-66 Drought on Long Island, New York, Geological Survey Water-Supply Paper 1879-F, 1969, Government Printing Office, Washington, D.C.

- C-32 Coleman, N.L., "Flume Studies of the Sediment Transfer Coefficient," Water Resources Research, Vol. 6, No. 3, pp. 801-809, June 1970.
- C-33 College of Engineering, University of Illinois, "Nitrate and Water Supply: Source and Control," Proceedings of 12th Sanitary Engineering Conference on Nitrate and Water Supply, p. 195, February 1970.
- C-34 Committee on Environmental Quality Management, ASCE, "Engineering Evaluation of Virus Hazard in Water," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 96, No. 1, pp. 111-161, February 1970.
- C-35 Conkling, H., "Utilization of Ground Water Storage in Stream System Development," Transactions, ASCE, Vol. III, pp. 275-305, 1946.
- C-36 Conner, J.T., Secretary of Commerce, "Zero Discharge: National Goal or National Calamity," Congressional Record, Vol. 118, No. 10, pp. E638-640, January 31, 1972.
- C-37 Cosper, H.R., "Economic Determinants for Sediment Management on a North Mississippi Watershed," Conference of the Water Resources Research Institute, Vicksburg, Mississippi, pp. 29-40, April 1971.
- C-38 Council on Environmental Quality, Environmental Quality, (third annual report), 1972, U.S. Government Printing Office, Washington, D.C.
- C-39 Craun, G.F., and L.J. McCabe, "Review of the Causes of Waterborne Disease Outbreaks," Journal, American Water Works Association, Vol. 65, No. 1, pp. 74-84, January 1973.
- C-40 Criddle, Wayne D., Karl Harris, and Lyman S. Willardson, "Consumptive Use and Water Requirements for Utah," State of Utah Technical Publication (8), p. 30, 1952, Salt Lake City, Utah.
- C-41 Criddle, W.D., K. Harris, and L.S. Willardson, "Consumptive Use and Water Requirements for Utah," Technical Publication 8 (Revised), 1962, State of Utah, Office of the State Engineer, Salt Lake City, Utah.
- C-42 Culp, R., and Culp, G., Advanced Wastewater Treatment, 1971, Van Nostrand Reinhold Co., New York, N.Y.
- C-43 Cyrus Wm. Rice and Company, "Engineering Economic Study of Mine Drainage Control Techniques," Appendix B to Acid Mine Drainage in Appalachia, 1969, a report by the Appalachian Regional Commission.
- D-1 Daly, R.F., and A.C. Egbert, "A Look Ahead for Food and Agriculture," Agricultural Economic Research, Vol. 18, No. 1, pp. 1-9, 1966.
- D-2 Dantzig, G., Linear Programming and Extensions, 1963, Princeton University Press, Princeton, New Jersey.

- D-3 David, Elizabeth L., "Public Perceptions of Water Quality," Water Resources Research, Vol. 7, No. 3, pp. 453-457, June 1971.
- D-4 Davidson, R.K., V.L. Smith, and Jay W. Wiley, Economics: An Analytical Approach, p. 460, 1962, Richard D. Irwin, Inc., Homewood, Illinois.
- D-5 Davis, L.H., R.A. Christensen, and S.H. Richards, Utah Farm Planning Manual, 1972, Utah Agricultural Experiment Station publication in manuscript form, Utah State University, Logan, Utah.
- D-6 Davis, R.K., The Range of Choice in Water Management, p. 196, 1968, Resources for the Future, through the Johns Hopkins Press.
- D-7 Davis, R.K., The Range of Choice in Water Management -- A Study of Dissolved Oxygen in the Potomac Estuary, 1968, The Johns Hopkins Press, for RFF.
- D-8 Davis, R.K., The Range of Choice in Water Quality Management, 1968, Johns Hopkins University Press, Baltimore, Md.
- D-9 Dawes, Julius H., "Tools for Water Resource Study," Journal of the Irrigation and Drainage Division, ASCE, Vol. 96, No. IR4, Proc. Paper 7720, pp. 403-424, December 1970.
- D-10 Daws, Julius H., and Wathne, Magne, "Cost of Reservoirs in Illinois," Circular 96, 1968, Illinois State Water Survey, Urbana, Illinois.
- D-11 Dawson, John A., "The Productivity of Water in Agriculture," Journal of Farm Economics, Vol. 39, pp. 1244-1252, 1957.
- D-12 DeGeer, M.W., et al., "Chloride Control -- Arkansas and Red River Basins," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 94, No. 1, pp. 117-128, February 1968.
- D-13 Deininger, Rolf A., and Westfield, James D., "Estimation of the Parameters of Gumbel's Third Asymptotic Distribution by Different Methods," Water Resources Research, Vol. 5, No. 6, pp. 1238-1243, December 1969.
- D-14 Deininger, R.A. Water Quality Management: The Planning of Economically Optimal Pollution Control Systems, 1965, Systems Research Memo. 125, The Technological Institute, Northwestern Univ., Evanston, Illinois.
- D-15 Deloach, R.E., and E.C. Tsivoglou, "Oxygen Sag and Stream Self-Purification," Journal Water Pollution Control Federation, Vol. 43, No. 6, pp. 1236-1243, June 1971.
- D-16 de Lucia, Russell, "The North Atlantic Regional Supply Mode," April 1971, presented at the 52nd Annual Meeting, American Geophysical Union, Washington, D.C.

- D-17 Department of Engineering, University of Syracuse, "Benefits of Water Quality Enhancement," December 1974, EPA-WPC Research Series.
- D-18 Deutch, Morris, "Controlled Induced Recharge Tests at Kalamazoo, Michigan," Journal American Water Works Association, Vol. 54, No. 2, pp. 181-196, February 1962.
- D-19 Dingman, S.L., and A.H. Johnson, "Pollution Potential of Some New Hampshire Lakes," Water Resources Research, Vol. 7, No. 5, pp. 1208-1215, October 1971.
- D-20 Dinius, S.H., "Social Accounting for Evaluating Water Resources," Water Resources Research, Vol. 8, No. 5, pp. 1159-1177, October 1972.
- D-21 Division of Water Resources, Department of Natural Resources, State of Utah, "Interim Report on the State Water Plan," Staff Report No. 6, p. 44, 1970, Salt Lake City, Utah.
- D-22 Dixon, N., and D.W. Hendricks, "Simulation of Spatial and Temporal Changes in Water Quality within a Hydrologic Unit," Water Resources Bulletin, Vol. 6, No. 4, pp. 483-497, July-August 1970.
- D-23 Dobbins, W.E., "BOD and Oxygen Relationships in Streams," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 90, No. 3, June 1964.
- D-24 Dolson, F.E., "In-Line Booster Stations," Proceedings of the Sixth Sanitary Engineering Conference, Urbana, Illinois, Vol. 62, No. 33.
- D-25 Dominion News, January 12, 1971, Morgantown, W. Va.
- D-26 Dominy, F.E., "Partial Solutions -- The Outlook," Water and Western Destiny: From Conflict to Cooperation, pp. 54-58, 1969, Proceedings of the Third Western Interstate Water Conference, Colorado State University.
- D-27 Dorfman, R., P.A. Samuelson, and R.M. Solow, Linear Programming and Economic Analysis, p. 527, 1958, McGraw-Hill Book Company, Inc., New York, N.Y.
- D-28 Dorr-Oliver, Inc., Cost of Wastewater Treatment Processes (Report No. TWRC-6 for the Robert Taft Water Research Center, US Department of Interior, Federal Water Pollution Control Administration, 1968, distributed by NTIS of US Department of Commerce, Springfield, Va.
- D-29 Dougal, M.D., E.R. Baumann, and J.F. Timmons, Physical and Economic Factors Associated with the Establishment of Stream Water Quality Standards, Vol. 2, pp. 343 and 646, April 1970.
- D-30 Dracup, J.L., The Optimum Use of a Ground-Water and Surface-Water System: A Parametric Linear Programming Approach, Water Resources Center Contribution No. 167, July 1966, University of California, Davis.

- D-31 Drew, H.R., and J.R. Tilton, "Thermal Requirements to Protect Aquatic Life in Texas Reservoirs," Journal, Water Pollution Control Federation, Vol. 42, No. 4, pp. 562-572, April 1970.
- D-32 Drobny, Neil, "Linear Programming Applications in Water Resources," Water Resources Bulletin, Vol. 7, No. 6, pp. 1180-1193, December 1971.
- D-33 Drobney, Neil L., "Water Resources Systems Analysis--An Overview," Proceedings of the Fourth American Water Resources Conference, pp. 534-558, November 18-22, 1968, American Water Resources Association, Urbana, Illinois.
- D-34 Duffin, R.J., E.L. Peterson, and C.M. Zener, Geometric Programming, p. 278, 1967, John Wiley and Sons, Inc., New York, N.Y.
- E-1 Eastman, J., and C. ReVelle, "Linear Decision Rule in Reservoir Management and Design: 3, Direct Capacity Determination and Intraseasonal Constraints," Water Resources Research, Vol. 9, No. 1, pp. 29-42, February 1973.
- E-2 Echelberger et al., "Disinfection of Algal-Laden Waters," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 97, No. 5, pp. 721-730, October 1971.
- E-3 Eckenfelder, W.W.Jr., and C.E. Adams, "Design and Economics of Joint Wastewater Treatment," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 98, No. 1, pp. 153-167, February 1972.
- E-4 Eckstein, O., "A Survey of the Theory of Public Expenditure Criteria," J.M. Buchanan ed., Public Finances: Needs, Sources and Utilization, 1961 National Bureau of Economic Research, Princeton Univ. Press.
- E-5 Economic Report of the President, House Document 238, 90th Congress, 2nd Session. transmitted to Congress, pp. 261-267, February 1968.
- E-6 Edison Water Quality Laboratory, Environmental Protection Agency, Environmental Impact of Highway Deicing, p. 120, June 1971.
- E-7 Eichberger, Willis G., Industrial Water Use, U.S. Department of Health, Education, and Welfare. Public Health Service, Washington, D.C.
- E-8 Eilers, R.G., Condensed One-Page Cost Estimates for Wastewater Treatment, November 1970, EPA.
- E-9 Eliassen, R., "Coliform Aftergrowths in Chlorinated Storm Overflows," Journal, Sanitary Engineering Division, ASCE Proceedings, Vol. 94, No. 2, pp. 371-380, April 1968.
- E-10 Eller, J., D.L. Ford, and E.F. Gloyne, "Water Reuse and Recycling in Industry," Journal, AWWA, Vol. 62, No. 3, pp. 149-151, March 1970.

- E-11 Eller, J., D.L. Ford, and E.F. Gloyna, "Water Reuse and Recycling in Industry," Journal, American Water Works Association, Vol. 62, No. 3, pp. 149-154, March 1970.
- E-12 Elmira Water Board, "Annual Report-1971," 1971, Elmira, New York.
- E-13 Environmental Protection Agency, Listing of 128 Waterborne Disease Outbreaks Known to Have Occurred in the U.S., 1961-1970, Cincinnati, Ohio.
- E-14 Environmental Protection Agency, Temperature Prediction in Stratified Water: Mathematical Model -- User's Manual, April 1971.
- E-15 EPA, Water Quality Criteria Data Book, in 4 volumes:
 Vol. I. Organic Chemical Pollution of Freshwater, December 1970
 Vol. II. Inorganic Chemical Pollution of Freshwater, July 1971
 Vol. III. Effects of Chemicals on Aquatic Life, May 1971
 Vol. IV. An Investigation into Recreational Water Quality, April 1972.
- E-16 Ernst and Ernst, "A Study of the Treatment of Water Quality Factors in Water Supply Analysis," p. 54, November 1972 (unpublished).
- E-17 Evans, D.R., and J.C. Wilson, "Capital and Operating Costs of Advanced Waste Treatment," Journal, Water Pollution Control Federation, Vol. 44, No. 1, pp. 1-13, January 1972.
- E-18 Eyer, John M., "Pumping Plant Operation and Maintenance Costs," Journal of the Irrigation and Drainage Division, ASCE, Vol. 91, No. IR4, pp. 37-58, December 1965.
- F-1 Faber, H.A., S.A. Bresler, and G. Walton, "Improving Community Water Supplies with Desalting Technology," Journal, AWWA, Vol. 64, No. 11, pp. 705-710, November 1972.
- F-2 Fair, G., Geyer, J., and Okun, D., Elements of Water Supply and Wastewater Disposal, 2nd ed., 1971, John Wiley & Sons, New York, N.Y.
- F-3 Fair, Gordon M., Geyer, John C., Okun, Daniel A., and Fiering, Myron B., Water and Wastewater Engineering, Vol. I, Water Supply and Wastewater Removal, 1968, John Wiley & Sons, Inc., New York, N.Y.
- F-4 Fair, Gordon M., Geyer, John C., and Okun, Daniel A., Elements of Water Supply and Wastewater Disposal, 1971, John Wiley & Sons, Inc., New York, N.Y.
- F-5 Faust, R.J., "Water Customers, Criteria, and Costs," Proceedings, Eleventh Sanitary Engineering Conference, February 1969, University of Illinois, Urbana, Illinois.
- F-6 Faustel, G.M., "Frought in New York State," Water & Water Engineering, Vol. 3, pp. 43-44, June; 45m July, 1966.

- F-7 Federal Power Commission, Water Requirements of Electric Utility Steam-Electric Generating Plants in 1959, Staff report based on 1959 Survey.
- F-8 Ferguson, C.E., Microeconomic Theory, 3rd ed., 1972, Homewood, Ill., R.D. Irwin, Inc.
- F-9 Fieldhouse, D.J. and Palmer, W.C., Meteorological and Agricultural Drought, Bulletin 353, February 1965, University of Delaware, Agricultural Experiment Station, Newark, Delaware.
- F-10 Fiering, M.B., "The Nature of the Storage-Yield Relationship," Symposium on Streamflow Regulation for Quality Control, pp. 243-252, 1965, R.A. Taft Sanitary Eng. Center, Cincinnati, Ohio.
- F-11 Fiering, M.B. and Jackson, B.B., "Synthetic Streamflows," Water Resources Monograph 1, 1971, American Geophysical Union, Washington, D.C.
- F-12 Fisher, D.W. et al., "Atmospheric Contributions to Water Quality of Streams in the Hubbard Brook Experimental Forest, N.H.," Water Resources Research, Vol. 4, No. 5, pp. 1115-1126, October 1968.
- F-13 Forste, Robert H. and Christensen, Robert L., "Economic Analysis of Public Water Supply in the Piscataqual River Watershed," Water Resources Research Center Bulletin No. 2, August 1968, University of New Hampshire, Durham, New Hampshire.
- F-14 Fosberg, R.F., "Restoration of Lost and Degraded Habitats," Future Environments of North America, by Darling, E., F. Fraser, and J.P. Milton, pp. 502-515, 1966.
- F-15 Foster, D.H., N.B. Hanes, and S.M. Lord, Jr., "A Critical Examination of Bathing Water Quality Standards," Journal, Water Pollution Control Federation, Vol. 43, No. 11, September 1971.
- F-16 Fowler, L.C., "Ground Water Management for the Nation's Future Water Resources Management through Ground Water Basin Operation," Journal of the Hydraulics Division, ASCE, Vol. 90, No. HY4, pp. 51-57, July 1964.
- F-17 Frankel, R.J., and W.W. Hansen, "Biological and Physical Responses in a Freshwater Dissolved Oxygen Model," Advances in Water Quality Improvement, Gloyna and Eckenfelder, Editors, University of Texas Press, pp. 126-140, 1966.
- F-18 Frankel, R.J., "Economics of Artificial Recharge for Municipal Water Supply," Artificial Recharge and Management of Aquifers, International Association of Scientific Hydrology, Publication No. 72, pp. 289-301, 1967.

- F-19 Fredrich, A.J., "Techniques for Evaluating Long-Term Reservoir Yields," 1969, Technical Paper No. 14, US Army Corps of Engineers, Hydrologic Engineering Center, Sacramento, California.
- F-20 Frost, T.P., "Practical Algae Control Methods for New Hampshire Water Supplies," Journal, N.H. Water Works Assoc., p. 7, April 1960.
- F-21 F.W.P.C.A., U.S. Dept. of the Interior, 1966, Delaware Estuary Comprehensive Study, Philadelphia, Pa.
- G-1 Gardner, B. Delworth, State Water Planning: Goals and Analytical Approaches, 1966, Bulletin 463, Utah Agricultural Experiment Station, Utah State University, Logan, Utah.
- G-2 Gavis, J., Wastewater Reuse, National Water Commission, p. 161, July 1971.
- G-3 Gershon, S.I., Unit Urban Water Use Model for the South Coastal Area, Technical Memorandum No. 27A, Revised January 1968, State of California, The Resources Agency, Department of Water Resources.
- G-4 Giglio, R.J., and R. Wrightington, "Methods for Apportioning Costs Among Participants in Regional Systems," Water Resources Research, Vol. 8, No. 5, pp. 1133-1144, October 1972.
- G-5 Gilbert, J.B., and P.N. Storrs, "Water Quality Planning and Management," Journal, AWWA, Vol. 62, No. 3, pp. 141-144, March 1970.
- G-6 Gillespie, G.J., "Save-the-Salmon Project on the St. John River," Fisheries of Canada, Vol. 20, No. 4, pp. 9-11, October 1967.
- G-7 Gisser, M., Introduction to Price Theory, p. 413, 1969, International Textbook Company, Scranton, Pennsylvania.
- G-8 Gisser, Micha, Linear Programming Models for Estimating the Agricultural Demand Function for Imported Water in the Pecos River Basin, Water Resources Research, Vol. 6, No. 4, pp. 1025-1032. 1970.
- G-9 Gold, R.L., J.H. Milligan, and C.G. Clyde, Formulation of a Mathematical Model for the Allocation of Colorado River Waters in Utah, PRWG73-1, p. 39, 1969, Utah Water Research Laboratory, Utah State University, Logan, Utah.
- G-10 Goodman, A.S., and R.J. Tucker, "Time-Varying Mathematical Model for Water Quality," Water Research, Vol. 5, No. 5, pp. 227-241, May 1971.
- G-11 Gordon, Y., Water Quality Management -- Agricultural Aspect, The Mitre Corporation, p. 36, December 1971.
- G-12 Government of the District of Columbia, Department of Sanitary Engineering, Regulations Prohibiting Certain Uses of Water from the District of Columbia Water Supply, September 20, 1966.

- G-13 Grincham, G.R., J.C. Schaefer, and E.E. Pyatt, "Water Quality Simulation Model," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 97, No. 5, pp. 569-585, October 1971.
- G-14 Graves, G.W., and G.B. Hatfield, "Mathematical Programming for Regional Water Quality Management," Water Resources Research, Vol. 8, No. 2, pp. 273-290, April 1972.
- G-15 Graves, G.W., G.B. Hatfield, and A. Winston, "Water Pollution Control Using By-Pass Piping," Water Resources Research, Vol. 5, No. 1, pp. 13-47 and 227-241, February 1969.
- G-16 Grossman, I., "Experiences with Surface Water Quality Standards," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 94, No. 1, pp. 13-19, February 1968.
- G-17 Grundy, R.D., "Strategies for Control of Man-Made Eutrophication," Environmental Science and Technology, Vol. 5, No. 12, pp. 1184-1190, December 1971.
- G-18 Gunbel, F., "Statistical Forecast of Droughts," Bulletin, International Association of Scientific Hydrology, Vol. 8, No. 1, 5, April 1963.
- G-19 Gutmanis, I., Personal Communication of May 9, 1973.
- H-1 Haas, J.E., "Optimal Taxing for the Abatement of Water Pollution," Water Resources Research, Vol. 6, No. 2, pp. 353-365, April 1970.
- H-2 Hadley, G., Linear Programming, p. 520, 1962, Addison-Wesley Publishing Co., Inc., Reading, Massachusetts.
- H-3 Hadley, G., Nonlinear and Dynamic Programming, p. 484, 1964, Addison-Wesley Publishing Co., Inc., Reading, Massachusetts.
- H-4 Hall, W.A., W.S. Butcher, and A. Esogbue, "Optimization of the Operation of a Multi-Purpose Reservoir by Dynamic Programming," Water Resources Research, Vol. 4, No. 3, pp. 471-477, 1968.
- H-5 Hall, W.A., "Optimum Design of a Multiple Purpose Reservoir," ASCE, Journal of the Hydraulics Division, Vol. 90, HY4, pp. 141-149, 1964.
- H-6 Hall, W.A., R.W. Shepard, W.S. Butcher, A.M. Esogbue, S.C. Parikh, G. Risch, and T.R. Rolfs, Optimum Operations for Planning of a Complex Water Resources System, p. 75, 1967, Water Resources Center, University of California, Los Angeles, California.
- H-7 Hall, W., and Dracup, J., Water Resources and Systems Engineering, 1970, McGraw-Hill Book Co., New York, N.Y.
- H-8 Hanes, N.B., and A.J. Forsa, "A Quantitative Analysis of the Effects of Bathing on Recreational Water Quality," presented at the Fifth International Water Pollution Research Conference (unpublished), July 1969.

- H-9 Hanke, S.H., "Demand for Water Under Dynamic Conditions," Water Resources Research, Vol. 6, No. 5, pp. 1253-1261, October 1970.
- H-10 Hanke, Steve H., The Demand for Water Under Dynamic Conditions: A Case Study of Boulder, Colorado, 1969. A Thesis submitted to the faculty of the Graduate School of the University of Colorado, Boulder, Colorado.
- H-11 Hanke, S.H., "Some Behavioral Characteristics Associated with Residential Water Price Changes," Water Resources Research, Vol. 6, No. 5, pp. 1383-1386, October 1970.
- H-12 Hartman, Bruno J., "Types and Uses of Water Storage," Journal, American Water Works Association, Vol. 51, No. 3, pp. 395-398, March 1959.
- H-13 Hartman, L.M., and Norman Whittlesey, Marginal Values of Irrigation Waters, pp. 1-28, 1960, Technical Bulletin 70, Colorado Agricultural Experiment Station, Fort Collins, Colorado.
- H-14 Hartung, H.O., "Revisions to the 1962 Drinking Water Standards," Willing Water, pp. 12-14, August 1973.
- H-15 Haveman, R.H., Ex-Post Analysis of Water Resource Projects, 1971, Johns Hopkins Univ. Press, Baltimore, Md.
- H-16 Haveman, R.H., "Ex-Post Benefit-Cost Analysis: The Case of Public Investments in Navigation Facilities," in Joint Economics Committee Subcommittee on Priorities and Economy in Government, Benefit-Cost Analysis of Federal Programs, U.S. GPO 1973.
- H-17 Havens, A. Vaughn, Snow, W. Brewster, Horowitz, Joseph L., and Liu, Chin-Shu, Drought Frequency, Intensity, and Duration: Its Correlation to Streamflow and Its Impact Upon Synthetic Hydrology, Technical Report on Project No. 27-4516, April 1968, Office of Water Resources Research, Rutgers, The State University, New Brunswick, New Jersey.
- H-18 Havens, A. Vaughn, The Economic Impact of Drought on Water Supply Systems in the Passaic River Basin, New Jersey, December 1969, New Jersey Agricultural Experiment Station, College of Agriculture and Environmental Science, Rutgers, The State University, New Brunswick, New Jersey.
- H-19 Haycock, E.B., Review of State Water Planning Activities, p. 29, January 4, 1968, Presentation to Coordinating Council of Natural Resources, Salt Lake City, Utah.
- H-20 Heidelberg College, Tiffin, Ohio, Water Quality Control Through Flow Augmentation, 1971.
- H-21 Heiple, Loren R., "Water Quality Management in the Pulp and Paper Industry." Ph.D. Thesis, June 1967, Civil Engineering, Stanford University, Palo Alto, California.

- H-22 Helfgott, T., J.V. Hunter, and D. Rickert, "Analytic and Process Classification of Effluents," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 96, No. 3, pp. 779-803, June 1970.
- H-23 Helfgott, T., J.V. Hunter, and D. Rickert, "Analytical and Process Classification of Effluents," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 96, No. SA 3, pp. 779-803, June 1970.
- H-24 Henderson, J., and Quandt, R., Microeconomic Theory--A Mathematical Approach, 2nd ed., 1971, McGraw-Hill Book Co., New York, N.Y.
- H-25 Henderson, J.M., "Water Pollution -- Facts and Fantasies," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 98, No. 3, pp. 529-546, June 1972.
- H-26 Hershfield, David M., "Generalizing Dry-Day Frequency Data," Journal of the American Water Works Association, Vol. 62, No. 1, January 1970.
- H-27 Hill, R.A., "Geographical Patterns in Coachella Valley, Calif.," American Geophysical Union Transcripts, Vol. 21, pp. 46-49, 1940.
- H-28 Hillier, F.S., and Lieberman, G.J., Introduction to Operations Research, 1967, Holden-Day, San Francisco.
- H-29 Hinomoto, Hirohide, "Unit and Total Cost Functions for Water Treatment Based on Koenig's Data," Water Resources Research, Vol. 7, No. 5, pp. 1064-1069, October 1971.
- H-30 Hirshleifer, Jack, DeHaven, James C., and Milliman, Jerome W., Water Supply, 1961, The University of Chicago Press, Chicago, Illinois.
- H-31 Hirshleifer, J., De Haven, J., and Milliman, J., Water Supply: Economics, Technology, and Policy, 1969, The University of Chicago Press, Chicago, Illinois.
- H-32 Hiskey, H.H., "Optimal Allocation of Irrigation Water: The Sevier River Basin," Ph.D. Dissertation, p. 163, 1972, Utah State University, Logan, Utah.
- H-33 Hofmann, Walter and Rantz, S.E., "What is Drought?" Journal of Soil and Water Conservation, pp. 105-106, May-June 1968.
- H-34 Hogan, W.T., F.E. Reed, and A.W. Starbird, Mechanical Aeration Systems for Rivers and Ponds, EPA, Water Pollution Control Research Series, p. 134, November 1970.
- H-35 Holeman, J.N., "The Sediment Yield of Major Rivers of the World," Water Resources Research, Vol. 4, No. 4, pp. 737-747, August 1968.
- H-36 Holland, C.T., et al., "Factors in the Design of an Acid Mine Drainage Treatment Plant," Second Symposium on Coal Mine Drainage Research, pp. 274-290, 1968, Ohio River Valley Sanitation Commission, Pittsburgh, Pa.

- H-37 Horowitz, Ira, Decision Making and the Theory of the Firm, 1970, Holt, Rinehart and Winston, New York, N.Y.
- H-38 Howe, C.W., Benefit-Cost Analysis for Water System Planning, 1972, American Geophysical Union Water Resources Monograph 2, Publication Press, Inc., Baltimore, Md.
- H-39 Howe, Charles W. and Linaweaver, F.P., "The Impact of Price on Residential Water Demand and Its Relation to System Design and Price Structure," Water Resources Research, Vol. 3, No. 1, 1st Quarter, pp. 13-32, 1967.
- H-40 Howe, Charles W. and Easter, K. William, Interbasin Transfers of Water, 1971, The Johns Hopkins Press for Resources for the Future, Inc., Baltimore, Md.
- H-41 Howe, C.W., "Municipal Water Demands," Forecasting the Demands for Water, edited by Sewell and Bower, 1968, Ottawa Department of Energy, Mines and Resources.
- H-42 Howe, Charles W. and Bower, Blair T., "Policies for Efficient Regional Water Management," Journal of the Irrigation and Drainage Division, Proceedings of the American Society of Civil Engineers.
- H-43 Howells, G.P., T.J. Kneipe, and M. Eisenbud, "Water Quality in Industrial Areas: Profile of a River," Environmental Science and Technology, Vol. 4, No. 1, pp. 26-35, January 1970.
- H-44 Howes, R.R., "Economic Analysis of Water Resource Development in the Susquehanna River Basin: An Application of Interregional Linear Programming," Ph.D. Dissertation, p. 250, 1966, University of Pennsylvania.
- H-45 Howson, Louis R., "Economics of Water Softening," Journal, American Water Works Association, Vol. 54, No. 2, pp. 161-162, February 1962.
- H-46 Hoyt, John C., Droughts of 1930-34, 1936, Government Printing Office, Washington, D.C.
- H-47 Huckabay, H.K., and A.G. Keller, "Aeration on an Inclined Transversely Corrugated Solid Surface," Journal, Water Pollution Control Federation, Vol. 42, No. 5, Part 2, pp. R202-R208, May 1970.
- H-48 Hufschmidt, M.M. and Fiering, M.B., Simulation Techniques for Design of Water-Resource Systems, 1966, Harvard University Press, Cambridge, Massachusetts.
- H-49 Hull, A.P., and J.T. Gilmartin, 1966 Environmental Monitoring of Radiation Levels at Brookhaven National Laboratory, B.N.L., p. 32, September 1969.

- H-50 Hunter, J.V., and W. Whipple, Jr., "Evaluating Instream Aeration of Polluted Rivers," Journal, Water Pollution Control Federation, Vol. 42, No. 8, Part 2, pp. R249-R262, August 1970.
- H-51 Hyslop, James, "Some Present Day Reclamation Problems: An Industrialist's Viewpoint," the Ohio Journal of Science, pp. 157-165, March 1964.
- I-1 IBM, Mathematical Programming System/360 Version 2, Linear and Separable Programming--User's Manual, Third Edition, GH 20-0476-2, p. 217, 1971, White Plains, New York.
- I-2 Intriligator, M.D., Mathematical Optimization and Economic Theory, p. 508, 1971, Prentice-Hall, Inc., Englewood Cliffs, New Jersey.
- I-3 Isaacs, W.P., and A.F. Gandy, Jr., "Atmospheric Oxygenation in a Simulated Stream," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 94, No. 2, pp. 319-344, April 1968.
- J-1 James, L. Douglas, and Robert R. Lee, Economics of Water Resources Planning, p. 615, 1971, McGraw-Hill Book Company, New York, N.Y.
- J-2 Jaske, R.T., and J.L. Spurgeon, "A Special Case, Thermal Digital Simulation of Waste Heat Discharges," Water Research, Vol. 2, pp. 777-802, 1968.
- J-3 Jaworski, N.A., Optimal Release Sequences for Water Quality Control in Multiple-Reservoir Systems, FWPCA Technical Paper No. 13, p. 231, 1968.
- J-4 Jaworski, N.A., W.J. Weber, and R.A. Deininger, "Optimal Reservoir Releases for Water Quality Control," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 96, No. 3, pp. 727-742, June 1970.
- J-5 Jehn, K.H., and Eddy, Amos, Summary Report of Workshop/Conference on Meteorological Drought, Report No. 4, May 1966, Atmospheric Science Group, College of Engineering, The University of Texas, Austin, Texas.
- J-6 Jeppson, R.W., Frequency Analysis and Probable Storage Requirements by Frequency Mass Curve Methods, PRWG35, p. 45, 1967, Utah Water Research Laboratory, Logan, Utah.
- J-7 Jewell, W.J., and P.L. McCarthy, "Aerobic Decomposition of Algae," Environmental Science and Technology, Vol. 5, No. 10, pp. 1023-1031, October 1971.
- J-8 Johnson, C.C., "More Water Treatment Needed," Journal of Environmental Health, Vol. 33, No. 4, pp. 332-337, January 1971.
- J-9 Johnson, E.L., "Economics of Water Quality Management," Journal, AWWA, Vol. 60, No. 10, pp. 1122-1128, October 1968.
- J-10 Johnson, E.L., "A Study in the Economics of Water Quality Management," Water Resources Research, Vol. 3, No. 2, pp. 291-305, 1967.

- J-11 Johnson, J.A., "Division of Cost Responsibility for Wastewater Systems," Journal, Water Pollution Control Federation, Vol. 42, No. 3, pp. 341-353, March 1970.
- J-12 Johnson, J.D., and C.P. Straub, Development of a Mathematical Model to Predict the Role of Surface Runoff and Groundwater Flow in Overfertilization of Surface Waters, Minnesota Water Resources Research Center Bulletin 35, p. 176, June 1971.
- J-13 Johnson, J.F., Renovated Waste Water, Research Paper No. 135, p. 155, 1971, The University of Chicago, Department of Geography.
- J-14 Johnson, Richard L., "An Investigation of Methods for Estimating Marginal Values of Irrigation Water," Unpublished M.S. Thesis, p. 64, 1966, Utah State University, Logan, Utah.
- J-15 James, L.D., and Lee, R.R., Economics of Water Resources Planning, 1971, McGraw-Hill Book Company, New York, N.Y.
- J-16 Johnston, J., Econometric Methods, 2nd ed., 1972, McGraw-Hill Book Co., New York, N.Y.
- K-1 Kadel, J.O., Cooling Towers -- A Technological Tool to Increase Plant Site Potentials, a paper presented at the American Power Conference, Chicago, p. 15, April 1970.
- K-2 Katz, M., "The Effects of Pollution Upon Aquatic Life," Water and Water Pollution Handbook, pp. 297-328, 1971, Marcel Dekker, Inc., New York.
- K-3 Kazmann, R.G., "The Role of Aquifers in Water Supply," Transactions, American Geophysical Union, Vol. 32, No. 2, pp. 227-230, April 1951.
- K-4 Keith, J.E., J.C. Andersen, and C.G. Clyde, The Economic Efficiency of Interbasin Agricultural Water Transfers in Utah: A Mathematical Programming Approach, PRWG100-3, 1973, Utah Water Research Laboratory, Utah State University, Logan, Utah.
- K-5 King, A.B., J.C. Andersen, C.G. Clyde, and D.H. Hoggan, Development of Regional Supply Function and a Least-Cost Model for Allocating Water Resources in Utah: A Parametric Linear Programming Approach, PRWG100-2, p. 162, Utah Water Research Laboratory, Utah State University, Logan, Utah.
- K-6 King, D.L., "The Role of Carbon in Eutrophication," Journal, Water Pollution Control Federation, Vol. 42, No. 12, pp. 2035-2051, December 1970.
- K-7 Kittrell, F.W., A Practical Guide to Water Quality Studies of Streams, Federal Water Pollution Control Administration, Publication CWR-5, p. 135, 1969.

- K-8 Kneese, A.V., "Environmental Pollution, Economics and Policy," American Economic Review, Vol. 61, No. 2, pp. 153-166, May 1971.
- K-9 Kneese, A.V., and B.T. Bower, Managing Water Quality: Economics, Technology, Institutions, R.F.F., 1968, Johns Hopkins Univ. Press, Baltimore, Md.
- K-10 Koelzer, V.A., Desalting, U.S. National Water Commission, p. 112, May 1972.
- K-11 Koenig, L., "Conventional Use or Reuse -- A Cost Comparison," Urban Water Resources Planning and Management, Texas Water Resources Institute, pp. 129-152, September 1971.
- K-12 Koenig, Louis, "The Cost of Conventional Water Supply: Principles of Desalination," edited by K.S. Spiegler, pp. 515-550, 1966, Academic Press, New York.
- K-13 Koenig, Louis, "The Cost of Water Treatment by Coagulation, Sedimentation, and Rapid Sand Filtration," Journal American Water Works Association, Vol. 59, No. 3, pp. 290-336, March 1967.
- K-14 Koenig, L., and D. Ford, "Reuse Can be Cheaper Than Disposal," Water Reuse, AICHE, Series 78, Vol. 63, pp. 143-147, 1967.
- K-15 Koh, C.Y., and L.N. Fan, Mathematical Models for the Prediction of Temperature Distributions Resulting from the Discharge of Heated Water into Large Bodies of Water, p. 219, October 1971.
- K-16 Koivo, A.J., and G.R. Phillips, "On Determination of BOD and Parameters in Polluted Stream Models from DO Measurements Only," Water Resources Research, Vol. 8, No. 2, pp. 478-486, April 1972.
- K-17 Kollar, Konstantine L., and Brewer, Robert, "Water Requirements for Manufacturing," Journal of the American Water Works Association, Vol. 60, No. 10, pp. 1129-1140, October 1968.
- K-18 Kormanik, R.A., "Design of Two-Stage Aerated Lagoons," Journal, Water Pollution Control Federation, Vol. 44, No. 3, pp. 451-458, March 1972.
- K-19 Krutilla, J.V., and C.J. Cicchetti, "Benefit-Cost Analysis and Technologically-Induced Relative Price Changes: The Case of Environmental Irreversibilities," in 92nd Cong., 2nd Sess., Joint Com. Print, Benefit-Cost Analyses of Federal Programs, U.S. GPO, January 2, 1973.
- K-20 Krutilla, J.V., and O. Eckstein, Multiple-Purpose River Development, 1958, The Johns Hopkins University Press, Baltimore, Md.

- L-1 Lange, W., 'Effect of Carbohydrates on the Symbiotic Growth of Planktonic Blue-Green Algae with Bacteria," Nature, 1967.
- L-2 Lappenbusch, W.I., D.G. Watson, and W.I. Templeton, "In Situ Measurement of Radiation Dose in the Columbia River," Health Physics Journal, Vol. 21, No. 2, pp. 247-251, August 1971.
- L-3 Lawrance, C.H., K.G. Tranbarger, and R.A. Drahn, "Lopez Water Supply Project," Journal, AWWA, Vol. 63, No. 11, pp. 711-727, November 1971.
- L-4 Lee, R.D., J.M. Symons, and G.G. Robeck, "Watershed Human-Use Level and Water Quality," Journal, AWWA, Vol. 62, No. 7, pp. 412-422, July 1970.
- L-5 Leftowich, Richard H., The Price System and Resource Allocation, 3rd edition, 1966, Holt, Rinehart and Winston, New York, N.Y.
- L-6 Leopold, L.B., "An Improved Method for Size Distribution of Stream Bed Gravel," Water Resources Research, Vol. 6, No. 5, pp. 1357-1366, October 1970.
- L-7 Leopold, L.B., Quantitative Comparison of Some Aesthetic Factors Among Rivers, 1969, U.S.D.I., Geological Survey Circular 620, Washington, D.C.
- L-8 Levin, A.A., et al., Thermal Discharges: Ecological Effects, pp. 224-230, March 1972, Battelle Memorial Institute.
- L-9 Levin, G.V., et al., "Pilot-Plant Tests of Phosphate Removal Process," Journal, Water Pollution Control Federation, Vol. 44, No. 10, pp. 1940-1954, October 1972.
- L-10 Lewis, J.L., J.H. McDermott, and P.L. Taylor, "Making Information Out of Data," Journal, Water Pollution Control Federation, Vol. 43, No. 9, pp. 1902-1911, September 1971.
- L-11 Liebman, J.C., and D.H. Marks, "Balas Algorithm for Zoned Uniform Treatment," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 94, No. 4, pp. 585-593, August 1968.
- L-12 Liebman, J.C., "The Optimal Allocation of Stream Dissolved Oxygen Resources," Water Resources Research, Vol. 2, No. 3, pp. 581-591, Third Quarter, 1966.
- L-13 Linaweaver, F.P., and Clark, C. Scott, "Costs of Water Transmission," Journal, American Water Works Association, Vol. 56, No. 12, pp. 1549-1560, December 1964.
- L-14 Linaweaver, F.P., Jr., J.C. Geyer, and J.B. Wolff, Final and Summary Report on the Residential Water Use Project, June 1966, The Johns Hopkins University Press.

- L-15 Linaweaver, F.P.Jr., Geyer, John C., and Wolff, Jerome B., A Study of Residential Water Use, March 1971, a report prepared for the Technical Studies Program of the Federal Housing Administration, Department of Housing and Urban Development, The Johns Hopkins University, Baltimore, Md.
- L-16 Linaweaver, F.P., Geyer, John C., and Wolff, Jerome B., "Summary Report on the Residential Water Use Research Project," Journal American Water Works Association, Vol. 59, No. 3, pp. 267-282, March 1967.
- L-17 Linstedt, K.D., K.J. Miller, and E.R. Bennett, "Metropolitan Successive Use of Water," Journal, AWWA, Vol. 63, No. 10, pp. 610-615, October 1971.
- L-18 Linstedt, K.D., E.R. Bennett, and S.W. Work, "Quality Considerations in Successive Water Use," Journal, Water Pollution Control Federation, Vol. 43, No. 8, pp. 1681-1694, August 1971.
- L-19 Loehr, R.C., "Alternatives for the Treatment and Disposal of Animal Wastes," Journal, Water Pollution Control Federation, Vol. 43, No. 4, pp. 668-677, April 1971.
- L-20 Loehr, R.C., "Animal Wastes -- A National Problem," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 95, No. 2, pp. 189-221, April 1969.
- L-21 Loehr, R.C., "Drainage and Pollution from Beef Cattle Feedlots," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 96, No. 6, pp. 1295-1309, December 1970.
- L-22 Lof, G.O., and A.V. Kneese, The Economics of Water Utilization in the Beet Sugar Industry, Resources for the Future, p. 125, 1968, Johns Hopkins Press.
- L-23 Lofting, E.M., and P.H. McGauhey, Economic Evaluation of Water, Part III: An Interindustry Analysis of the California Water Economy, p. 83, 1963, Water Resources Center, University of California, Berkeley, California.
- L-24 Lofting, E.M., and P.H. McGauhey, Economic Evaluation of Water, Part IV: An Input-Output and Linear Programming Analysis of California Water Requirements, p. 187, 1968, Water Resources Center, University of California, Berkeley, California.
- L-25 Lohr, E.W., and Love, S.K., "The Industrial Utility of Public Water Supplies in the United States," 1952, Water Supply Paper 1299, 1954, U.S. Geological Survey, Washington, D.C.
- L-26 Lombardo, P.S., Critical Review of Currently Available Water Quality Models, July 1973, Hydromcomp, Inc., Palo Alto, California.

- L-27 Loucks, D.P., C.S. Revelle, and W.R. Lynn, Linear Programming Models for Water Pollution Control, Vol. 14, No. 4, pp. B166-188, 1967, Management Science.
- L-28 Loucks, D.P., and W.R. Lynn, "Probabilistic Models for Predicting Stream Quality," Water Resources Research, Vol. 2, No. 3, pp. 593-605, July-September 1966.
- L-29 Lynn, W.R., "Application of Systems Analysis to Water and Wastes Water Treatment," Journal of the American Water Works Association, Vol. 58, No. 6, pp. 651-656, 1966.
- L-30 Lynn, W.R., J.A. Logan, and A. Charnes, "Systems Analysis for Planning Waste Water Treatment Plants," Water Pollution Control Federation Journal, Vol. 34, No. 6, pp. 565-579, 1962.
- L-31 Lyons, D.N., and W.W. Eckenfelder, Jr., "Optimizing a Kraft Mill Water Reuse System," Chemical Engineering Progress, Vol. 67, No. 107, pp. 381-387, 1971.
- M-1 Maass, Arthur A., Maynard M. Hufschmidt, Robert Dorfman, Harold A. Thomas, Jr., Stephen A. Marglin, and Gordon Fair, Design of Water Resource Systems, p. 620, 1962, Harvard University Press, Cambridge, Mass.
- M-2 Magnuson, Marvin D., Meteorological Drought in Idaho as Expressed by the Palmer Index, February 1971, U.S. Department of Commerce, Environmental Science Services Administration, Weather Bureau, Western Region, Salt Lake City, Utah.
- M-3 Magnuson, M.D., Meteorological Drought in Montana as Expressed by the Palmer Index, February 1971, U.S. Department of Commerce, Environmental Science Services Administration, Weather Bureau, Western Region, Salt Lake City, Utah.
- M-4 Manne, A.S., Investments for Capacity Expansion, 1967, M.I.T. Press, Cambridge, Mass.
- M-5 Manwaring, J.F., M. Chaudhuri, and R.S. Engelbrecht, "Removal of Viruses by Coagulation and Flocculation," Journal, AWWA, Vol. 63, No. 5, pp. 298-300, May 1971
- M-6 Margolis, J., "Shadow Prices for Incorrect or Nonexistent Market Values," in U.S. Congress, 91st Congress, 1st Session, Joint Economic Committee, Subcommittee on Economics in Government, The Analysis and Evaluation of Public Expenditures: The PPB System, Joint Committee Print, 1969, U.S. GPO, Washington, D.C.
- M-7 Marks, D.H., Analysis Techniques in Thermal Pollution Management and a Case Study in Site Evaluation and System Planning, 1971, mimeographed report from the author, Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, Mass.
- M-8 Marks, D.H., and R.A. Borenstein, An Optimal Siting Model for Thermal Plants with Temperature Constraints, 1970, The Johns Hopkins University Department of Geography and Environmental Engineering, Baltimore, Md.

- M-9 Marx, A.J., "Pretreatment Basin for Algae Removal," Biology of Water Pollution, FWPCA, pp. 239-244, 1967.
- M-10 Matalas, Nicholas C., Autocorrelation of Rainfall and Streamflow Minimums, 1963, Government Printing Office, Washington, D.C.
- M-11 Matalas, N.C., Probability Distribution of Low Flows, 1963, Government Printing Office, Washington, D.C.
- M-12 Matson, A.J. et al, Economic Effects of Using Substandard Quality Water in Webster and Other Communities in South Dakota, Office of Saline Water R&D Progress Report No. 463, October 1969, USDI.
- M-13 Meier, W.L., and C.S. Beightler, "An Optimization Method for Branching Multi-Stage Water Resource Systems," Water Resources Research, Vol. 3, No. 3, pp. 645-652, 1967.
- M-14 Metcalf & Eddy, The Economic Value of Water Quality, Office of Saline Water R&D Progress Report No. 779, January 1972, USDI.
- M-15 Metcalf & Eddy, Inc., Wastewater Engineering, 1972, McGraw-Hill, N.Y.
- M-16 Metcalf & Eddy Engineers, The Water Quality Aspects of Future Supplemental Supplies, April 1967, a report to the East Bay Municipal Utility District, Oakland, California.
- M-17 Meva Corporation, Domestic Water Use Planning, October 1965, a report prepared for the Department of Water Resources, Resources Agency, State of California.
- M-18 Michel, Robert, "Costs and Manpower for Municipal Wastewater Treatment Plant Operation and Maintenance, 1965-1968," Journal of the Water Pollution Control Federation, Vol. 42, No. 11, pp. 1883-1910, November 1970.
- M-19 Millan, Jamie and Yevjevich, Vujica, "Probabilities of Observed Droughts," June 1971, Hydrology Paper, Colorado State University, Fort Collins, Colorado.
- M-20 Miller, David W., Water Atlas of the United States, Port Washington, L.I., New York, 1963, Water Information Center, Inc., New York.
- M-21 Miller, Stanley F., Larry L. Boersma, and Emery N. Castle, Irrigation Water Values in the Willamette Valley: A Study of Alternative Methods, Technical Bulletin 85, p. 34, 1965, Oregon Agricultural Experiment Station, Corvallis, Oregon.
- M-22 Miller, Thomas A., "Sufficient Conditions for Exact Aggregation in Linear Programming Models," Agricultural Economics Research, Vol. 18, No. 2, pp. 52-57, April 1966
- M-23 Miller, Thomas A., "Sufficient Conditions for Exact Aggregation in Linear Programming Models," Agricultural Economic Research, Vol. 43, No. 2, pp. 52-57, 1966, U.S. Department of Agriculture.

- M-24 Milligan, J.H., Optimizing Conjunctive Use of Groundwater and Surface Water, PRWG42-3T, p. 157, 1969, Utah Water Research Laboratory, Utah State University, Logan, Utah.
- M-25 Mishan, E.J., Welfare Economics: Ten Introductory Essays, p. 333, 1964, New York Random House.
- M-26 Mitchell, J. Murray, Jr., A Critical Appraisal of Periodicities in Climate, Office of Climatology, U.S. Weather Bureau, Washington, D.C.
- M-27 Mitchell, R.D., "Hudson River as a Water Source for New York City," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 94, No. 3, pp. 447-453, June 1968.
- M-28 Mitre Corp, A Technology Assessment Methodology, (Water Pollution: Domestic Wastes), Vol. 6, 1971, distributed by NTIS of U.S. Department of Commerce, Springfield, Va.
- M-29 Mitre Corp, Water Quality Indices, Pub. No. M72-54, 1972, The Mitre Corp., McLean, Va.
- M-30 Moore, C.V., "Economics of Water Demand on Commercialized Agriculture," Journal of the American Water Works Association, Vol. 54, No. 8, pp. 913-920, 1962.
- M-31 Moore, Charles V., and Trimble R. Hedges, "Farm Size in Relation to Resource Use, Earnings, and Adjustments on the San Joaquin Valley Eastside, Res. Rep. 263," Volume II of a four volume series, Economics of On-Farm Irrigation Water Availability and Costs, and Related Farm Adjustments, p. 40, 1963, California Agricultural Experiment Station, Giannini Foundation of Agricultural Economics, Berkeley, California.
- M-32 Moreau, David H., Economic Engineering Consultant, Chapel Hill, North Carolina, A Report on Estimating Local Drought Losses, July 1971.
- M-33 Mozes, D., "An Integral Approach to Urban Water Supply Systems," The Annals of Regional Science, Vol. 3, No. 1, pp. 115-124, June 1969.
- M-34 Mueller, Ph.D. Thesis due for publication, 1973, Johns Hopkins University, Baltimore, Md.
- M-35 Munson, W.C., "Estimating Consumptive Use by the Munson P.E. Index Method," Methods for Estimating Evapotranspiration, pp. 65-107, Nov 2-4, 1966. ASCE Irrigation and Drainage Specialty Conference, Las Vegas, Nevada.
- M-36 Murdoch, John H., "Quenching the Big Thirst," Public Works, February 1964.
- Mc-1 Mackenthun, K.M., and L.E. Keup, "Biological Problems Encountered in Water Supplies," Journal, American Water Works Association, Vol. 62, No. 8, pp. 520-526, August 1970.

- Mc-2 MacNish, Robert D., Randall, Allan D., and Ku, Henry F., "Water Availability in Urban Areas of the Susquehanna River Basin -- A Preliminary Appraisal," Report of Investigation RI-7, 1969, prepared by U.S. Geological Survey and State of New York Conservation Department--Water Resources Commission, Albany, New York.
- Mc-3 McCabe, L.J., J.M. Symons, R.D. Lee, and G.G. Robeck, "Survey of Community Water Supply Systems," Journal, AWWA, Vol. 62, No. 11, pp. 670-687, November 1970.
- Mc-4 McCullough, C.A., and R.R. Nicklen, "Control of Water Pollution During Dam Construction," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 97, No. 1, pp. 81-89, February 1971.
- Mc-5 McGauhey, P.H., Engineering Management of Water Quality, 1968, McGraw-Hill Book Co., New York, N.Y.
- Mc-6 McGuinness, C.L., The Role of Groundwater in the National Water Situation, United States Geological Survey Water Supply Paper 1800, pp. 864-886, 1963.
- Mc-7 McJunkin, Frederick E., "Population Forecasting by Sanitary Engineers," Journal of the Sanitary Engineering Division, ASCE, Vol. 90, No. SA4, Proc. Paper 3993, pp. 31-58, August 1964.
- Mc-8 McKee, J.E., and Wolf, H., Water Quality Criteria, 2nd ed., California State Water Quality Control Board Publication No. 3-A, 1963.
- Mc-9 McKee, V.C., "Optimal Land and Water Resource Development--A Linear Programming Application," Ph.D. Dissertation, p. 169, 1966, Iowa State University, Ames, Iowa.
- N-1 Nace, Raymond L., and Pluhowski, E.J., Drought of the 1950's with Special Reference to the Midcontinent, 1965, Government Printing Office, Washington, D.C.
- N-2 Nahavandi, A., and J. Campisi, "Parametric Study of Power Plant Thermal Pollution," Journal, Water Pollution Control Federation, Vol. 43, No. 3, pp. 506-514, March 1971.
- N-3 Namias, Jerome, "Nature and Possible Causes of the Northeastern United States Drought During 1962-65," Monthly Weather Review, Vol. 94, No. 9, pp. 543-554, September 1966.
- N-4 National Academy of Engineering, Engineering for Resolution of the Energy-Environment Dilemma, p. 340, 1972.
- N-5 National Association of Manufacturers and Chamber of Commerce of the United States, Water in Industry, January 1965.
- N-6 National Coal Association, Bituminous Coal Data, 1964, 1967, 1969, National Coal Association, Washington, D.C.

- N-7 National Coal Association, Steam Electric Plant Factors, 1968, 1969, Government Printing Office, Washington, D.C.
- N-8 National Industrial Pollution Control Council, Detergents, A Status Report, p. 16, March 1971.
- N-9 National Industrial Pollution Control Council, Wastewater Reclamation, GPO Report No. COM-71-50083, p. 31, March 1971.
- N-10 National Technical Advisory Committee (Report) to the Secretary of the Interior, Water Quality Criteria, 1968, Federal Water Pollution Control Federation, Washington, D.C., (reprinted by U.S.E.P.A., 1972).
- N-11 National Technical Advisory Committee to the Secretary of the Interior, Water Quality Criteria (Green Book), p. 234, April 1, 1968.
- N-12 Naylor, T.H., et al., Computer Simulation Techniques, 1966, John Wiley & Sons, New York.
- N-13 Nelson, E., and O.L. Harline, Utah's Changing Economic Patterns, p. 89, 1964, University of Utah Press, Salt Lake City, Utah.
- N-14 Nelson, J.L., and W.L. Haushild, "Accumulation of Radionuclides in Bed Sediments of the Columbia River Between the Hanford Reactors and McNary Dam," Water Resources Research, Vol. 6, No. 1, pp. 130-137, February 1970.
- N-15 Nemerow, N.L., and R.C. Faro, "Total Dollar Benefit of Water Pollution Control," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 96, No. 3, pp. 665-674, June 1970.
- N-16 New York State, "Demographic Projections for New York State Counties to 2020 A.D.," 1968, Albany, New York.
- N-17 New York University, School of Engineering and Science, Proceedings of the Conference on the Drought in the Northeastern United States, Sterling Forest, New York, May 1967, University Heights, New York, N.Y. March 1968.
- N-18 Nieswand, G.H., "The Conjunctive Use of Surface and Groundwaters in the Mullica River Basin, New Jersey: A Chance Constrained Linear Programming Approach," June 1970, Unpublished Ph.D. Thesis, Rutgers University, New Brunswick, New Jersey.
- N-19 Northwestern University, Department of Civil Engineering, Lake Michigan Development Proposal, p. 81, May 1969.
- O-1 O'Connor, D.J., and D.M. DiToro, "Photosynthesis and Oxygen Balance in Streams," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 96, No. SA2, pp. 547-571, April 1970.

- 0-2 O'Connor, D.J., "The Temporal and Spatial Distribution of Dissolved Oxygen in Streams," Water Resources Research, Vol. 3, No. 1, pp. 65-80, February 1967.
- 0-3 O'Connor, D.J., and J.A. Mueller, "A water-Quality Model of Chlorides in the Great Lakes," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 96, No. SA 4, pp. 955-975, August 1970.
- 0-4 O'Connor, P.J., "Comparison of Probability Distribution in an Analysis of Drought Flows," Water and Sewage Works, III, pp. 160-185, April 1964.
- 0-5 Office of Appalachian Studies, "The Incidence and Formation of Mine Drainage Pollution," Appendix C to the Report for Development of Water Resources in Appalachia, 1969.
- 0-6 Ohio Department of Health, Water Pollution Control Board, Water Quality Standards Adopted by the Board, December 9, 1969 (Amended April 14, 1970) for the Hocking River Basin, 1970, Ohio Department of Health, Columbus, Ohio.
- 0-7 Ohio Department of Industrial Relations, Division of Mines Annual Report, 1960-1969, State of Ohio, Columbus, Ohio.
- 0-8 Ohio River Valley Water Sanitation Commission, Coal Industry Advising Committee, Principles, Practices and Case Histories in the Control of Acid Mine Drainage, 1964, Ohio River Valley Water Sanitation Commission, Orsanco, Ohio. Includes recent supplementary case studies.
- 0-9 Orlob and Lindord, "Cost of Water Treatment in California," Journal, American Water Works Association, January 1958.
- 0-10 Orlob, G.T., Planning the Texas Water System, pp. 171-186, Feb 3-4, 1970, Fifth Annual Water Resources Research Conference, Washington, D.C.
- 0-11 Oskam, F., "A Kinetic Model of Phytoplankton Growth and Its Use in Algal Control by Reservoir Mixing," Proceedings of International Symposium on Man-Made Lakes, Their Problems and Environmental Effects, p. 21, May 1971, Knoxville, Tennessee.
- P-1 Pacific Southwest Interagency Committee, "Main report, Great Basin Region Comprehensive Framework Study," p. 60, 1971a, Salt Lake City, Utah.
- P-2 Pacific Southwest Interagency Committee, "Economic Base and Projections Appendix IV," Great Basin Region, Comprehensive Framework Study, p. 181, 1971a, Salt Lake City, Utah.
- P-3 Pacific Southwest Interagency Committee, "Economic Base and Projections Appendix IV," Great Basin Region, Comprehensive Framework Study, 1971a, Salt Lake City, Utah.

- P-4 Pacific Southwest Interagency Committee, "Economic Base and Projections, Appendix IV," Great Basin Region, Comprehensive Framework Study, p. 181, 1971b, Salt Lake City, Utah.
- P-5 Pacific Southwest Interagency Committee, "Land Resources and Use, Appendix VI," Great Basin Region, Comprehensive Framework Study, p. 143, 1971b, Salt Lake City, Utah.
- P-6 Pacific Southwest Interagency Committee, "Municipal and Industrial Water Supply, Appendix XI," Great Basin Region, Comprehensive Framework Study, 1971b, Salt Lake City, Utah.
- P-7 Pacific Southwest Interagency Committee, "Economic Base and Projections, Appendix IV," Upper Colorado Region Comprehensive Framework Study, p. 213, 1971c, Salt Lake City, Utah.
- P-8 Pacific Southwest Interagency Committee, "Irrigation and Drainage, Appendix X," Great Basin Region, Comprehensive Framework Study, p. 64, 1971c, Salt Lake City, Utah.
- P-9 Pacific Southwest Interagency Committee, "Water Resources, Appendix V," Great Basin Comprehensive Framework Study, p. 109, 1971d, Salt Lake City, Utah.
- P-10 Pacific Southwest Interagency Committee, "Economic Base and Projections, Appendix IV," Upper Colorado Region, Comprehensive Framework Study, p. 213, 1971d, Salt Lake City, Utah.
- P-11 Pacific Southwest Interagency Committee, "Municipal and Industrial Water Supply, Appendix XI," Great Basin Comprehensive Framework Study, p. 48, 1971d, Salt Lake City, Utah.
- P-12 Pacific Southwest Interagency Committee, "Economic Base and Projections, Appendix IV," Upper Colorado Region, Comprehensive Framework Study, p. 213, 1971c, Salt Lake City, Utah.
- P-13 Pacific Southwest Interagency Committee, "Water Resources, Appendix V," Upper Colorado Comprehensive Framework Study, p. 125, 1971c, Salt Lake City, Utah.
- P-14 Pacific Southwest Interagency Committee, "Land Resources and Use, Appendix VI," Upper Colorado Region, Comprehensive Framework Study, p. 142, 1971c, Denver, Colorado.
- P-15 Pacific Southwest Interagency Committee, "Land Resources and Use, Appendix VI," Great Basin Comprehensive Framework Study, p. 143, 1971f, Salt Lake City, Utah.
- P-16 Pacific Southwest Interagency Committee, "Irrigation and Drainage, Appendix X," Upper Colorado Region, Comprehensive Framework Study, p. 98, 1971f, Denver, Colorado.
- P-17 Pacific Southwest Interagency Committee, "Land Resources and Use, Appendix VI," Upper Colorado Comprehensive Framework Study, p. 142, 1971g, Salt Lake City, Utah.

- P-18 Pacific Southwest Interagency Committee, "Irrigation and Drainage, Appendix X," Upper Colorado Region, Comprehensive Framework Study, p. 98, 1971g, Denver, Colorado.
- P-19 Pacific Southwest Interagency Committee, "Irrigation and Drainage, Appendix X," Great Basin Comprehensive Framework Study, p. 64, 1971h, Salt Lake City, Utah.
- P-20 Pacific Southwest Interagency Committee, "Municipal and Industrial Water Supply," Appendix XI, Upper Colorado Comprehensive Framework Study, p. 62, 1971h, Salt Lake City, Utah.
- P-21 Pacific Southwest Interagency Committee, "Irrigation and Drainage," Appendix X, Upper Colorado Comprehensive Framework Study, p. 98, 1971i, Salt Lake City, Utah.
- P-22 Pacific Southwest Interagency Committee, "Electric Power," Appendix XIV, Upper Colorado Comprehensive Framework Study, p. 92, 1971i, Salt Lake City, Utah.
- P-23 Pacific Southwest Interagency Committee, "Municipal and Industrial Water Supply," Appendix XI, Great Basin Comprehensive Framework Study, p. 48, 1971j, Salt Lake City, Utah.
- P-24 Pacific Southwest Interagency Committee, "Municipal and Industrial Water Supply, Appendix XI, Upper Colorado Comprehensive Framework Study, p. 62, 1971k, Salt Lake City, Utah.
- P-25 Pacific Southwest Interagency Committee, "Electric Power," Appendix XIV, Upper Colorado Comprehensive Framework Study, p. 92, 1971l, Salt Lake City, Utah.
- P-26 Palmer, Wayne C., Meteorological Drought, Research Paper No. 45, February 1965, U.S. Department of Commerce, Weather Bureau, Washington, D.C.
- P-27 Parker, D.C., and J.A. Crutchfield, "Water Quality Management and the Time Profile of Benefits and Costs," Water Resources Research, Vol. 4, No. 2, pp. 233-246, April 1968.
- P-28 Parker, F.L., and P.A. Krenkel, Editors, Engineering Aspects of Thermal Pollution, August 1968, Proceedings of the National Symposium on Thermal Pollution, Sponsored by FWPCA and Vanderbilt University, Nashville, Tenn., Vanderbilt University Press, 1969.
- P-29 Parker, F.L., and P.A. Krenkel, Thermal Pollution: Status of the Art, Report No. 3, pp. 380 & 550, December 1969, Vanderbilt University.
- P-30 Patterson, W.L., and R.F. Bunker, Communities of Over 1000 Population with Water Containing in Excess of 1000 ppm of Total Dissolved Solids, U.S. Office of Saline Water Research and Development Progress Report No. 462, p. 47, October 1969.
- P-31 Patterson, W.L., and R.F. Bunker, Economic Effects of Mineral Content in Municipal Water Supplies, U.S. Office of Saline Water Research and Development Progress Report No. 260, p. 162, May 1967.

- P-32 Perez, A.I., J.C. Schaaake, and E.E. Pyatt, "Simulation Model for Flow Augmentation Costs," Journal, Hydraulic Div., ASCE Proceedings, Vol. 96, No. 1, pp. 131-142, January 1970.
- P-33 Peterson, B.E., and R.T. Jaske, A Test Simulation of Potential Effects of Thermal Power Plants on Streams in the Upper Mississippi River Basin, Battelle Memorial Institute Northwest Laboratory Report No. 999, p. 75, December 1968.
- P-34 Phelps, E.B., Stream Sanitation, p. 155, 1944, Wiley, New York.
- P-35 Picton, Walter L., "Water Use in the United States 1900-1980," March 1960, U.S. Department of Commerce, Business and Defense Services Administration.
- P-36 Piper, A.M., "A Graphic Procedure in the Geochemical Interpretation of Water Analyses," American Geophysical Union Transcripts, Vol. 25, pp. 914-923, 1944.
- P-37 Polk, B.M., B.A. Benedict, and F. Parker, "Cooling Water Density Wedges in Streams," Journal, Hydraulics Div., ASCE Proceedings, Vol. 97, No. HY 10, pp. 1639-1652, October 1971.
- P-38 Porter, J.W., Economics of Combining Distilled Sea Water and Renovated Wastewater as a New Source of Municipal Water Supply, Office of Saline Water R&D Progress Report No. 617, p. 97, October 1970.
- P-39 Presnell, M.W., and J.J. Miescier, "Coliforms and Fecal Coliforms in an Oyster-Growing Area," Journal, Water Pollution Control Federation, Vol. 43, No. 3, pp. 407-416, March 1971.
- P-40 Provencial, J. Andre, "Emergency Measures Due to the Drought, The Fitchburg, Massachusetts Story," New England Water Works Journal, pp. 231-235, September 1965.
- P-41 Pugh, C.A., Project Manager, Pacific Southwest Interagency Committee, Lower Colorado Region State-Federal Interagency Group. A written summary of published and unpublished materials concerning acreages and land classifications for irrigated and potentially irrigable land in Washington and Kane Counties, Utah, 1971.
- P-42 Purdy, R.W., "What Do We Know About Natural Purification?" Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 94, No. 1, pp. 1-11, February 1968.
- Q-1 Quirk, T.P., and L.J. Eder, "Evaluation of Alternative Solutions for Achievement of River Standards," Journal, Water Pollution Control Federation, Vol. 42, No. 2, pp. 272-290, February 1970.
- R-1 Raiffa, Howard, Decision Analysis, 1968, Addison-Wesley, Reading, Massachusetts.
- R-2 Rapier, P.M., "Ultimate Disposal of Brines from Municipal Wastewater Renovation," Chemical Engineering Progress, Symposium Series, Vol. 67, No. 107, pp. 340-351, 1971.

- R-3 Reeves, T.G., "Nitrogen Removal: A Literature Review," Journal, Water Pollution Control Federation, Vol. 44, No. 10, pp. 1895-1908, October 1972.
- R-4 Reichle, D.E., P.B. Dunaway, and D.J. Nelson, "Turnover and Concentration of Radionuclides in Food Chains," Nuclear Safety, Vol. 11, No. 1, pp. 43-55, January-February 1970.
- R-5 Reichle, D.E., D.J. Nelson, and P.B. Dunaway, Biological Concentration and Turnover of Radio-Nuclides in Food Chains: A Bibliography, Oak Ridge National Laboratory, p. 42, July 1971.
- R-6 ReVelle, C., E. Joeres, and W. Kirby, "The Linear Decision Rule in Reservoir Management and Design: 1, Development of the Stochastic Model," Water Resources Research, Vol. 5, No. 4, pp. 767-777, August 1969.
- R-7 ReVelle, C., and W. Kirby, "The Linear Decision Rule in Reservoir Management and Design: 2, Performance Optimization," Water Resources Research, Vol. 6, No. 4, pp. 1033-1044, August 1970.
- R-8 ReVelle, C., D. Loucks, and W.R. Lynn, "Linear Programming Applied to Water Quality Management," Water Resources Research, Vol. 4, No. 1, pp. 1-9, February 1968.
- R-9 ReVelle, C., D. Loucks, and W.R. Lynn, "A Management Model for Water Quality Control," Journal, Water Pollution Control Federation, Vol. 39, No. 6, June 1967.
- R-10 Rey, G., W.J. Lacy, and A. Cywin, "Industrial Water Reuse: Future Pollution Solution," Environmental Science and Technology, Vol. 5, No. 9, pp. 760-765, September 1971.
- R-11 Rice, D.P., Estimating the Cost of Illness, Public Health Service, HEW, Health Economics Series No. 6, May 1966 (out of print).
- R-12 Rice, R.M., and G.T. Foggin, III, "Effect of High Intensity Storms on Soil Slippage on Mountainous Watersheds in Southern California," Water Resources Research, Vol. 7, No. 6, pp. 1485-1496, December 1971.
- R-13 Richardson, E.A., 1971, State Climatologist. Personal discussions from July 1971 to December 1971.
- R-14 Richardson, William H., "Intake Construction for Large Lakes and Rivers," Journal, American Water Works Association, Vol. 61, No. 8, pp. 365-371, August 1969.
- R-15 Rippl, W., "The Capacity of Storage Reservoirs for Water Supply," Proceedings, Institute of Civil Engineers, Vol. 71, pp. 270-278, 1883.
- R-16 Robbins, J.W.D., D.H. Howells, and G.J. Kriz, "Stream Pollution from Animal Production Units," Journal, Water Pollution Control Federation, Vol. 44, No. 8, pp. 1536-1544, August 1972.

- R-17 Rogers, J.P., and R.S. Gemmel, "Economic Evaluation of Flow Augmentation: A Systems Analysis Case Study," Proceedings of the 21st Industrial Waste Conference, pp. 568-580, 1966, Purdue University, Lafayette, Indiana.
- R-18 Rorabaugh, M.I., "Ground Water in Northeastern Louisville, Kentucky: With Reference to Induced Recharge," Water Supply Paper 1360-B, 1956, U.S. Geological Survey, Washington, D.C.
- R-19 Rossie, J.P., and E.A. Cecil, Research on Dry-Type Cooling Towers for Thermal Electric Generation, 321 pages, November 1970, Beck and Associates, Denver, Colorado.
- R-20 Russell, Clifford S., The Definition and Measurement of Drought Losses: The Northeast Drought of 1962-66, Proceedings of the Fourth American Water Resources Conference, July 1969.
- R-21 Russell, C.S., D.G. Arey, and R.W. Kates, Drought and Water Supply: Implications of the Massachusetts Experience for Municipal Planning, p. 256, 1970, Johns Hopkins University Press.
- S-1 Saarinen, Thomas F., Perception of the Drought Hazard on the Great Plains, Research Paper No. 106, 1966, The University of Chicago, Department of Geography, Chicago, Illinois.
- S-2 Saladarriaga, S., and Yevjevich, V., "Application of Run-Lengths to Hydrologic Series," Hydrology Paper No. 40, April 1970, Colorado State University, Fort Collins, Colorado.
- S-3 Samuelson, P.A., Economics, 8th Ed., 1970, McGraw-Hill, New York.
- S-4 Santee County Water District, California, Total Water Use, p. 16, 1968.
- S-5 Savage, W.F., "A Review of Desalination Processes and Product Water Costs," Water Resources Research, Vol. 6, No. 5, pp. 1449-1453, October 1970.
- S-6 Sayers, W.T., "Water Quality Surveillance: The Federal-State Network," Environmental Science and Technology, Vol. 5, No. 2, pp. 114-119, February 1971.
- S-7 Schaake, John C., Jr., "A Model for Estimating Regional Water Needs," Presented at the 52nd Annual Meeting, April 1971, American Geophysical Union, Washington, D.C.
- S-8 Schneider, William J., "Water Resources of the Appalachian Region-- Pennsylvania to Alabama," Hydrologic Investigation Atlas HA-198, 1965, U.S. Geological Survey, Washington, D.C.
- S-9 Schuh, G.E., "The Over-Valuation of the Dollar and U.S. Agricultural Development: A Re-Interpretation of the Post World War II Period and a Look to the Future," unpublished paper, 1973, Agricultural Economics Department, Purdue University, LaFayette, Indiana.
- S-10 Schwenn, A., and J.A. Cole, "Optimal Control of Linked Reservoirs," Water Resources Research, Vol. 4, No. 3, pp. 479-497, June 1968.

- S-11 Seelye, Elwyn E., Data Book for Civil Engineers Design, Volume I, 1959, John Wiley & Sons, Inc., New York.
- S-12 Select Committee on National Water Resources, United States Senate, Water Resources Activities in the United States, Water Supply and Demand, Pursuant to Senate Resolution 48, 86th Congress, August 1960, Government Printing Office, Washington, D.C.
- S-13 Select Committee on Water Resources, U.S. Senate, Paper No. 21, p. 130, 1958.
- S-14 Shafer, P., Chief, Land Resources and Laboratory Branch, Region 4, Bureau of Reclamation, 1971, A written summary of published and unpublished materials relating to land classifications and acreages of irrigated and potentially irrigable land in the Great Basin and Upper Colorado Regions of the Comprehensive Framework Studies.
- S-15 Shafer, Paul, Chief, Land Resources and Laboratory Branch, Region 4, Bureau of Reclamation, 1972, Personal consultation during February 1972.
- S-16 Shailendra, C.P., and R.W. Shepard, "Linear Dynamic Decomposition Programming Approach to Long Range Optimization of Northern California Water Resource System, Part I: Deterministic Hydrology," 1967, Operations Research Center, College of Engineering, University of California, Berkeley, California.
- S-17 Shannon, E.E., and P.L. Brezonik, "Eutrophication Analysis: A Multivariate Approach," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 98, No. 1, pp. 37-57, February 1972.
- S-18 Sharp, J.V.A., R.L. Bateman, and J.A. Westphal, Digital Simulation Model of Inorganic Water Quality of Tahoe-Truckee System, Nevada-California, University of Nevada, Hydrology and Water Resources Publication No. 6, p. 21, April 1970.
- S-19 Shien, Y.S., and B. Davidson, "Direct Field Determination of the Natural Reaeration Coefficient by Frequency Response Analysis," Water Resources Research, Vol. 7, No. 6, pp. 1522-1528, December 1971.
- S-20 Simons, T.J., "Multi-Layered Models of Currents, Temperature, and Water Quality Parameters in the Great Lakes," Proceedings of the International Symposium on Modeling Techniques in Water Resource Systems, Vol. 1, pp. 150-159, May 1972.
- S-21 Smith, F.E., "Effects of Enrichment in Mathematical Models," Eutrophication: Causes, Consequences, Correctives, pp. 631-645, 1969, National Academy of Sciences.
- S-22 Smith, Robert, "Cost of Conventional and Advanced Treatment of Wastewater," Journal, Water Pollution Control Federation, Vol. 40, No. 9, pp. 1516-1574, September 1968.

- S-23 Smith, Robert, "Cost of Conventional and Advanced Treatment of Wastewater," Journal, American Water Works Association, Vol. 60, No. 9, pp. 1546-1573, September 1968.
- S-24 Smith, R., "Cost-Effectiveness Task Force -- Economics of Consolidating Sewage Treatment Plants by Means of Interceptor Sewers and Force Mains," unpublished, p. 52, March 1971.
- S-25 Smith, R., Costs of Wastewater Renovation, undated, EPA.
- S-26 Smith, Vernon, Investment and Production, 1966, Harvard University Press, Cambridge, Massachusetts.
- S-27 Sobel, M.J., Chebyshev Optimal Waste Discharges, Report No. 17, p. 28, September 1969, Yale University, Department of Administrative Sciences.
- S-28 Sobel, M.J., "Water Quality Improvement Programming Problem," Water Resources Research, Vol. 1, No. 4, pp. 477-487, 1965.
- S-29 Spofford, W.O., and H.A. Thomas, Jr., "A Least-Cost Evaluation of Disposal Systems for Low-Level Liquid Radioactive Wastes," Operations Research in Disposal of Liquid Radioactive Wastes in Streams, Part 2, p. 33, December 1967, Harvard Water Resources Group.
- S-30 Sproul, O.J., "Virus Inactivation by Water Treatment," Journal, AWWA, Vol. 64, No. 1, pp. 31-35, January 1972.
- S-31 Stale, J.B., and Neill, J.C., "Calculated Risks of Impounding Reservoir Yield," ASCE Proceedings 89 [HY 1 No. 3385], pp. 25-34, January 1963.
- S-32 Starr, Martin Kenneth, Product Design and Decision Theory, 1963, Prentice-Hall, Inc., Englewood Cliffs, New Jersey.
- S-33 State Engineer, State of Utah, Hearings before the State Engineer, Kaiparowitz Plateau Power Project, p. 450, 1964, Salt Lake City, Utah.
- S-34 Steiner, P.O., "The Role of Alternative Cost in Project Design and Selection," Quarterly Journal of Economics, Vol. 79, No. 3, pp. 417-431, August 1965.
- S-35 Stephen, Robert W., and Walter C. Lorenz, "Survey of Cost on Methods for Control of Acid Mine Drainage Pollution," Attachment E of Appendix C to Acid Mine Drainage in Appalachia, a report by the Appalachian Regional Commission, 1969.
- S-36 Stewart, C.C., "Recent Land and Groundwater Development in Utah Under the Desert Land Act," Utah Agricultural Experiment Station Bulletin 412, p. 29, 1960, Utah State University, Logan, Utah.

- S-37 Stewart, J. Ian, and Robert M. Hagan, "Predicting Effects of Water Shortage on Crop Yield," Journal of the Irrigation and Drainage Division, ASCE, No. IRI, Proc. Paper 6443, Vol. 95, pp. 91-104, 1969.
- S-38 Stigler, George J., The Theory of Price, p. 355, 1966, The Macmillan Company, London.
- S-39 Stone, R., W. Garber, and H. Friedland, "Water Quality: Cost Benefits of Irreducibles," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 96, No. 3, pp. 691-697, June 1970.
- S-40 Streeter, N.W., and E.B. Phelps, US Public Health Service, Bulletin No. 146, 1925.
- S-41 Strommen, N.D., Van Den Brink, C., and Kidder, E.H., Meteorological Drought in Michigan, Research Report No. 78, February 1969, Michigan State University, Agricultural Experiment Station, East Lansing, Michigan.
- S-42 Strommen, N.D., Purvis, John C., and Kish, Alex J., Meteorological Drought in South Carolina as Expressed by Palmer Index, April 1966, U.S. Department of Commerce, Environmental Science Services Administration, Weather Bureau.
- S-43 "Study of Domestic Water Use," Journal of the American Water Works Association, Vol. 50, p. 1408, November 1958.
- S-44 Stults, Harold M., "Predicting Farmer Response to a Falling Water Table: An Arizona Case Study," Proceedings of a Conference on Water Resources and Economic Development of the West, Rep 15, p. 13, December 1966, Committee on the Economics of Water Resources Development of the Western Agricultural Economics Research Council, Las Vegas, Nevada.
- S-45 Suhr, L.G., "Some Notes on Reuse," Journal, AWWA, Vol. 63, No. 10, pp. 630-633, October 1971.
- S-46 Syracuse University Department of Civil Engineering, Benefits of Water Quality Enhancement, EPA Water Pollution Control Research Series No. 16110-0A-J, December 1970, U.S. Government Printing Office, Washington, D.C.
- T-1 Tanji, K.K., and J.W. Biggar, "Specific Conductance Model for Natural Waters and Soil Solutions of Limited Salinity Levels," Water Resources Research, Vol. 8, No. 1, pp. 145-153, February 1972.
- T-2 Taylor, A.C., "An Efficient Water Quality Control," Paper presented at the XIX Int. Meeting of the Institute of Man. Sci., April 8, 1972, Houston, Texas.
- T-3 Terry, S.L., "Reclamation and Industrial Reuse of Amarillo's Wastewater," Journal, American Water Works Association, Vol. 63, No. 3, pp. 162-167, March 1971.

- T-4 Texas Water Development Board, Simulation of Water Quality in Streams and Canals, Report No. EPA-OWP-TEX-QUAL-1, September 1970.
- T-5 Texas Water Development Board, Simulation of Water Quality in Streams and Canals, Report No. EPA-OWP-TEX-DOSAG-1, September 1970.
- T-6 Thackston, E.L., and P.A. Krenkel, "Reaeration Prediction in Natural Streams," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 95, No. 1, pp. 65-94, February 1969.
- T-7 Thayer, R.P., and R.G. Krutchkoff, "Stochastic Model for BOD and DO in Streams," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 93, No. SA3, pp. 59-72, June 1967.
- T-8 Thomann, R.V., "Recent Studies from a Mathematical Model of Water Pollution Control in the Delaware Estuary," Water Resources Research, Vol. 1, No. 3, pp. 349-359, 1965.
- T-9 Thomann, R.V., Systems Analysis and Water Quality Management, 1972, Environmental Research and Applications Corp, New York.
- T-10 Thomas, H.A., and R. Nevelle, "On the Efficient Use of the High Aswan Dam for Hydropower and Irrigation," Management Science, Vol. 12, pp. B296-311, 1966.
- T-11 Thompson, T.L., P.E. Snoek, and E.J. Wasp, "Economics of Regional Waste Transport and Disposal Systems," Chemical Engineering Progress, Vol. 67, No. 107, pp. 413-422, 1971.
- T-12 Todd, David Keith, Ground Water Hydrology, 1969, John Wiley & Sons, Inc., New York.
- T-13 Todd, D.K., The Water Encyclopedia, 1970, Water Information Center, Port Washington, New York.
- T-14 Tsivoglou, B.C., "Nuclear Power: The Social Conflict," Environmental Science and Technology, Vol. 5, No. 5, pp. 404-410, May 1971.
- T-15 Turney, W.G., "Control of Pollution from Pleasure Boats," Journal, Water Pollution Control Federation, Vol. 43, No. 3, pp. 447-453 March 1971.
- T-16 Tweeten, L., Foundations of Farm Policy, p. 577, 1970, University of Nebraska Press, Lincoln, Nebraska.
- T-17 Tyson, H.N., Jr., and Weber, E.M., "Ground Water Management for the Nation's Future-Computer Simulation of Ground Water Basins," Journal of the Hydraulics Division, ASCE, Vol. 90, No. HY4, pp. 59-77, July 1964.
- U-1 University of Pennsylvania, A Method for Integrating Surface and Groundwater in Humid Regions, Unpublished, 1973.
- U-2 "Urban Domestic Water Consumption," Journal of the American Water Works Association, Vol. 31, pp. 2003-2014, December 1939.

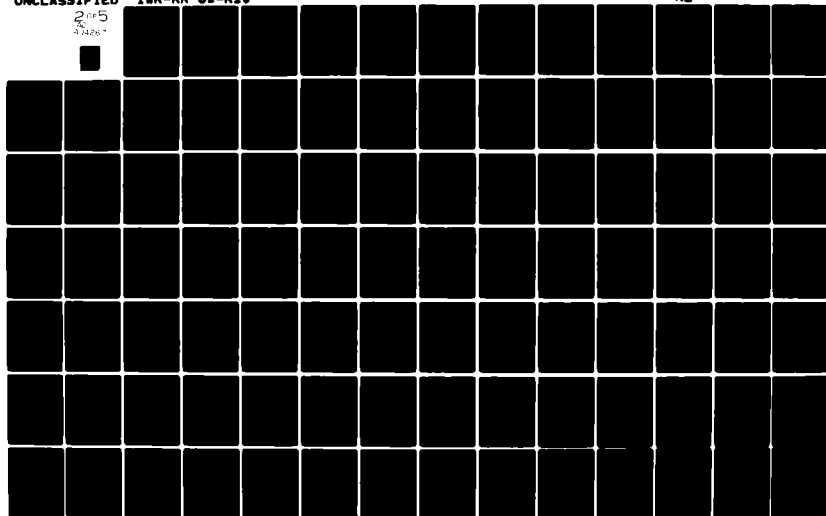
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- U-3 Urquhart, Leonard C., Civil Engineering Handbook, Fourth Edition, 1959, McGraw-Hill Book Company, Inc., New York.
- U-4 U.S. Army Corps of Engineers, "Elmira, New York, Section No. 2, Seepage Relief Project, Analysis of Design," Elmira, New York, Flood Control Project, February 1951, Baltimore District, Baltimore, Maryland.
- U-5 U.S. Army Corps of Engineers, "Monthly Streamflow Analysis," Computer Program 24-J2-L 242, 1966, Hydrologic Engineering Center, Sacramento, California.
- U-6 U.S. Army Corps of Engineers, "Monthly Streamflow Analysis, Computer Program 24-J2-L 243, 1966, Hydrologic Engineering Center, Sacramento, California.
- U-7 U.S. Army Corps of Engineers, "Report for Development of Water Resources in Appalachia," Appendix E, October 1968, Office of Appalachian Studies, Baltimore District, Baltimore, Maryland.
- U-8 U.S. Bureau of Mines, Oil Shale Mining, Rifle, Colorado, 1944-56, Bulletin 611, p. 168, 1958, U.S. Government Printing Office, Washington, D.C.
- U-9 U.S. Bureau of Reclamation, "Central Utah Project, Initial Phase," Bonneville Unit Definite Plan Report, p. 191, 1964, Salt Lake City, Utah.
- U-10 U.S. Bureau of Reclamation and Office of Saline Water, Desalting Handbook for Planners, May 1972.
- U-11 U.S. Congress, Committee on Interior and Insular Affairs, Hearings On the Northeast Water Crisis, 89th Congress, 1st Session, September 8, 1965.
- U-12 U.S. Department of Agriculture, Soil Conservation Service, Irrigation Water Requirements, 1967, Technical Release 21, Washington, D.C.
- U-13 U.S. Department of Agriculture, "Preliminary Projections of Economic Activity in the Agricultural, Forestry, and Related Economic Sectors of the United States and Its Water Resource Regions, 1980, 2000, and 2020," p. 92, 1967, U.S. Government Printing Office, Washington, D.C.
- U-14 U.S. Department of Agriculture, Restoring Surface-Mined Land, Miscellaneous Publication No. 1082, April 1968, Government Printing Office, Washington, D.C.
- U-15 U.S. Department of Agriculture, Seedskaadee Project, Wyoming, Colorado River Storage Project: A Report of Reappraisal of Direct Agricultural Benefits and Project Impacts, pp. 19-22, 1958, USDA Field Advisory Committee and USDA Field Party, Salt Lake City, Utah.

- U-16 U.S. Department of Agriculture, Utah Department of Natural Resources, Water and Related Land Resources, Sevier River Basin, Utah, p. 247, 1969, Salt Lake City, Utah (a joint report).
- U-17 U.S. Department of the Army, Potomac River Basin Report, Vol. 1, February 1969, Government Printing Office, Washington, D.C. 1970
- U-18 U.S. Department of Commerce, Bureau of the Census, By States, 1967 Census of Manufactures, September 1970, Government Printing Office, Washington, D.C.
- U-19 U.S. Department of Commerce, Bureau of the Census, 1969 Census of Agriculture, Vol. 1, Part 44, p. 278, 1969, Utah.
- U-20 U.S. Department of Commerce, Bureau of the Census, 1970 Census of Population, Number of Inhabitants, Pennsylvania, 1971, Government Printing Office, Washington, D.C.
- U-21 U.S. Department of Commerce, Bureau of the Census, 1964 United States Census of Agriculture, Vol. 1, Part 44, p. 299, 1964, Utah.
- U-22 U.S. Department of Commerce, Bureau of the Census, Water Use in Manufacturing, 1963 Census of Manufacturers, 1966, Government Printing Office, Washington, D.C.
- U-23 U.S. Department of Commerce, Bureau of the Census, United States Census of Housing, 1970, Pennsylvania, Government Printing Office, Washington, D.C.
- U-24 U.S. Department of Commerce, Bureau of the Census, Statistical Abstract of the United States, 1970, 91st Annual Edition, Government Printing Office, Washington, D.C.
- U-25 U.S. Department of Commerce, Business and Defense Services Administration, Regional Construction Requirements for Water and Wastewater Facilities 1955-1967-1980, October 1967, Washington, D.C.
- U-26 U.S. Department of Commerce, Environmental Science Services Administration, Weather Bureau, Meteorological Drought In Virginia, December, 1965.
- U-27 U.S. Department of Commerce, Water Industries and Engineering Services Division, Business and Defense Services Administration, Water Use by Appalachian Manufacturers 1964, December 1967.
- U-28 U.S. Department of Commerce, Weather Bureau, Rainfall Frequency Atlas of the United States, Technical Paper No. 40, May 1961, Washington, D.C.
- U-29 U.S. Department of Health, Education and Welfare, Public Health Service, Environmental Health Service, Bureau of Water Hygiene, Community Water Supply Study, New York, New York, Standard Metropolitan Statistical Area, 1970.

- U-30 U.S. Department of Health, Education and Welfare, Community Water Supply Study, Significance of National Findings, July 1970, Washington, D.C.
- U-31 U.S. Department of Health, Education and Welfare, Public Health Service, Manual of Septic-Tank Practice, Public Health Service Publication No. 526, developed in cooperation with the Joint Committee on Rural Sanitation, 1957, Government Printing Office, Washington, D.C.
- U-32 U.S. Department of Health, Education and Welfare, Public Health Service Drinking Water Standards, USPHS Pub. No. 956, 1962, Revised 1962, Washington, D.C.
- U-33 U.S. Department of the Interior, Bureau of Reclamation, "Central Utah Project, Initial Phase, Bonneville Unit," Definite Plan Report, Appendix E, Agricultural Economy, pp. 43-45, 1964.
- U-34 U.S. Department of the Interior, Bureau of Reclamation, "Emery County Project, Utah, Definite Plan Report, Appendix D; Agricultural Economy, Economic Justification and Financial Analysis, Plan Formulation, p. 66, 1961.
- U-35 U.S. Department of the Interior, Federal Water Pollution Control Administration, Industrial Waste Guide on Thermal Pollution, Sep 1968, Northwest Region, Pacific Northwest Water Laboratory, Corvallis, Oregon.
- U-36 U.S. Department of the Interior, Geological Survey, Water Resources Division, Instructions for Using the Punch Card System for Storage and Retrieval of Ground Water Data, 1967, Washington, D.C.
- U-37 U.S. Department of the Interior, "Manual of Procedures and Methods for Calculating Comparative Costs of Municipal Water Supply from Saline and Conventional Water Sources in Texas," Report No. 257, November 1966.
- U-38 U.S. Department of Interior, "Stream Pollution by Coal Mine Drainage in Appalachia," Attachment A of Appendix C, Acid Mine Drainage in Appalachia, a report by the Appalachian Regional Commission, 1969.
- U-39 U.S. Department of the Interior, Bureau of Reclamation, "Vernal Unit, Central Utah Project, Definite Plan Report," Appendix D, Agricultural Economy, Financial Analysis, p. 15, 1957.
- U-40 U.S. Federal Power Commission, 1970 National Power Survey, Part IV, p. 184, 1971, U.S. Government Printing Office, Washington, D.C.
- U-41 U.S. National Academy of Engineering, Committee on Power Plant Siting, Engineering for Resolution of the Energy-Environment Dilemma, Environmental Protection of Water, pp. 103-136, Environmental Protection Against Radiation, pp. 151-223, 1972.
- U-42 U.S. Office of Saline Water, The Economic Value of Water Quality, Research and Development Progress Report No. 779, p. 223, January 1972.

- U-43 U.S. Public Health Service, Community Water Supply Study -- Analysis of National Survey Findings, p. 111, undated 1969 survey.
- U-44 U.S. Public Health Service, Drinking Water Standards, PHS Publication No. 956, p. 61, 1962.
- U-45 U.S. Public Health Service, Drinking Water Standards 1962, U.S. Department of Health, Education and Welfare, Public Health Service Publication No. 56, 1962, Washington, D.C.
- U-46 U.S. Senate, Oil Shale Development: Hearings Before the Senate, p. 92, 1965, U.S. Government Printing Office, Washington, D.C.
- U-47 U.S. Senate, Oil Shale Development: Hearings Before the Senate, p. 557, 1970, U.S. Government Printing Office, Washington, D.C.
- U-48 U.S. Senate, Oil Shale Development: Hearings Before the Senate, p. 97, 1972, U.S. Government Printing Office, Washington, D.C.
- U-49 U.S. Senate, 87th Congress, 2d Session, Doc. 97, Policies, Standards and Procedures in the Formulation, Evaluation and Review of Plans for Use and Development of Water and Related Land Resources, 1962, U.S. GPO, Washington, D.C.
- U-50 U.S. Soil Conservation Service, Tekamah-Mud Creek Watershed, Nebraska, 36 pages, December 1971.
- U-51 U.S. Water Resources Council, The Nation's Water Resources, First National Assessment, p. 419, 1968, Washington, D.C.
- U-52 U.S. Water Resources Council, The Nation's Water Resources, 1968, Washington, D.C.
- U-53 U.S. Water Resources Council, Drought in Northeastern United States, A Third Appraisal, A Report to the President, March 1, 1966, Washington, D.C.
- U-54 U.S. Water Resources Council, "Preliminary Report on Economic Projections for Selected Geographic Area, 1929 to 2020," Vol. 1, p. 125, 1968, U.S. Government Printing Office, Washington, D.C.
- U-55 U.S. Water Resources Council, Procedures for the Evaluation of Water and Related Land Resource Projects, 1969, Washington, D.C.
- U-56 U.S. Water Resources Council, Reappraisal of Drought in Northeastern United States, A Report to the President, September 7, 1969, Washington, D.C.
- U-57 U.S. Weather Bureau, Rainfall Frequency Atlas of the U.S. for Durations from 30 Minutes to 24 Hours and Return Periods from 1 to 100 Years, Technical Paper No. 40, 1961, Government Printing Office, Washington, D.C.
- U-58 Upton, C., The Economics of Pollution, Chicago University, Graduate School of Business, Selected Paper No. 36, p. 11, 1970.

- U-59 Upton, C., "A Model of Water Quality Management Under Uncertainty," Water Resources Research, Vol. 6, No. 3, pp. 690-699, June 1970.
- U-60 Utah Conservation Needs Committee, Utah Conservation Needs, Inventory Report, p. 91, 1970, U.S. Department of Agriculture, Soil Conservation Service, Salt Lake City, Utah.
- U-61 Utah Division of Water Resources, Interim Report on State Water Plan, p. 44, 1970, Staff Report No. 6, Salt Lake City, Utah.
- U-62 Utah Division of Water Resources--United States Department of the Interior, Geological Survey, "Groundwater Conditions in Utah, Spring of 1965," Cooperative Investigations Report No. 3, p. 99, 1965, Utah Department of Natural Resources, Salt Lake City, Utah.
- U-63 Utah Division of Water Resources--United States Department of the Interior, Geological Survey, "Groundwater Conditions in Utah, Spring of 1966," Cooperative Investigations Report No. 4, p. 95, 1966, Utah Department of Natural Resources, Salt Lake City, Utah.
- U-64 Utah Division of Water Resources--United States Department of the Interior, Geological Survey, "Groundwater Conditions in Utah, Spring of 1967," Cooperative Investigations Report No. 5, p. 89, 1967, Utah Department of Natural Resources, Salt Lake City, Utah.
- U-65 Utah Division of Water Resources--United States Department of the Interior, Geological Survey, "Groundwater Conditions in Utah, Spring of 1968," Cooperative Investigations Report No. 6, p. 105, 1968, Utah Department of Natural Resources, Salt Lake City, Utah.
- U-66
- U-67 Utah Division of Water Resources--United States Department of the Interior, Geological Survey, "Groundwater Conditions in Utah, Spring of 1969," Cooperative Investigations Report No. 7, p. 61, 1969, Utah Department of Natural Resources, Salt Lake City, Utah.
- U-68 Utah State University--Utah Department of Natural Resources, Hydrologic Atlas of Utah, PRWG35-1, p. 306, 1968, Utah Water Research Laboratory, Logan Utah (a joint report).
- U-69 Utah State University--Utah Division of Water Resources, Hydrologic Inventory of the Bear River Study Unit, PRWG8, 1972, Utah Water Research Laboratory, Logan, Utah (a joint study), in publication.
- U-70 Utah State University--Utah Division of Water Resources, Hydrologic Inventory of the Uinta Study Unit, PRWG40-5, p. 182, 1970a, Utah Water Research Laboratory, Logan, Utah (a joint report).
- U-71 Utah State University--Utah Division of Water Resources, Hydrologic Inventory of the Weber River Study Unit, PRWG40-6, p. 131, 1970b, Utah Water Research Laboratory, Logan, Utah (a joint report).

- U-72 Utah Water and Power Board, and Utah State University, Developing a State Water Plan: Utah's Water Resources--Problems and Needs--A Challenge, PR-EC4Bg-2, p. 122, 1963, Utah State University, Logan, Utah.
- V-1 Varga, L.P., and C.P. Falls, Continuous System Models of Oxygen Depletion in a Eutrophic Reservoir, p. 33, undated, Oklahoma State University.
- V-2 Vaughn, S.H., "New and Used Water for Industrial Needs--Where and When," Proceedings, International Association of Great Lakes Research, pp. 567-570, 1970.
- V-3 Velz, C.J., "Deoxygenation and Reoxygenation," ASCE Transactions, Vol. 104, p. 560, 1939.
- V-4 Velz, C.J., et al., "Pumped Storage for Water Resources Development," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 94, No. 1, pp. 159-170, February 1968.
- V-5 Vincent, J.R., and J.D. Russell, "Alternatives for Salinity Management in the Colorado River Basin," Water Resources Bulletin, Vol. 7, No. 4, pp. 856-866, August 1971.
- V-6 Virgil, J., S. Warburton, W.W. Haynes, and L.R. Kaiser, "Nitrates in Municipal Water Supply Cause Methemoglobinemia in Infants," Public Health Reports, Vol. 80, No. 12, p. 1119, December 1965.
- V-7 Viskanta, R., and J.S. Toor, "Radiant Energy Transfer in Water," Water Resources Research, Vol. 8, No. 3, pp. 595-608, June 1972.
- W-1 Waddell, W.W., et al., A Dynamic Hydraulic and Water Quality Model for River Basins, Pacific Northwest Laboratories, Battelle Memorial Institute, January 1973.
- W-2 Waelti, J.J., and R.C. Lewis, The Water Quality Controversy in Minnesota and the Marginal Costs of Alternative Levels of Water Quality in the Upper Mississippi River, p. 19, 1971, University of Minnesota, Water Resources Research Center.
- W-3 Wagner, H.M., Principles of Operations Research with Applications to Managerial Decisions, 1969, Prentice Hall, Englewood Cliffs, New Jersey.
- W-4 Wagner, R.J., Factors Affecting Municipal and Industrial Water Use, Technical Memorandum No. 20, October 1966, The Resource Agency, State of California, Department of Water Resources.
- W-5 Walton, William C., Ground Water Resource Evaluation, 1970, McGraw-Hill Book Co., New York.

- W-6 Walton, William C., Hills, David L., and Grudeen, Gordon M., "Recharge from Induced Stream Bed Infiltration Under Varying Ground Water-Level and Stream-Stage Conditions," Water Resources Research Center Bulletin No. 6, June 1967, University of Minnesota, St Paul, Minnesota.
- W-7 Wanielista, Martin P., "An Evaluation of Water Treatment Plant Design and Operation," Ph.D. Thesis, January 1971, Civil Engineering, Cornell University, Ithica, New York.
- W-8 Wanielista, M.P., and L.M. Falkson, "Flexibility in Water-Treatment Plant Design," Journal, AWWA, Vol. 63, No. 5, pp. 281-283, May 1971.
- W-9 Water Resources Council, "Proposed Principles and Standards for Planning Water and Related Land Resources," Federal Register, Vol. 36, No. 245, December 21, 1971, Washington, D.C.
- W-10 Water Resources Research Institute, Rutgers University, Oxygen Regeneration of Polluted Rivers: The Passaic River, New Jersey, March 1971.
- W-11 Water Resources Research Center, University of Minnesota, "Lake Eutrophication--Water Pollution Causes, Effects and Control," Save the Lakes Symposium, Bulletin No. 22, p. 61, 1970.
- W-12 Water Resources Work Group, Great Basin Region, Comprehensive Framework Study, Appendix V, Water Resources, p. 109, 1971, Pacific Southwest Inter-Agency Committee, Salt Lake City, Utah.
- W-13 Weedfall, Robert O., Meteorological Drought in West Virginia, 1969, U.S. Department of Commerce, Environmental Science Services Administration, ESSA Technical Memorandum EDSTM 11, Silver Spring, Maryland.
- W-14 Weeter, D.W., A Water Quality Prediction Model and a Water Quality Simulation Program for the Wabash River, p. 271, January 1971, Ph.D. Thesis, Purdue University.
- W-15 "Wells, Rivers Both Help Process Companies Cope with Drought," Chemical Engineering, May 9, 1966.
- W-16 West Penn Power Company, "General Power Service-Schedule 30," May 1971, Bellefonte, Pennsylvania.
- W-17 Wetterhall, W.S., "The Ground Water Resources of Chemung County, New York," Bulletin G.W.-40, 1959, New York Power and Control Commission, Albany, New York.
- W-18 Whipple, W., et al, Instream Aeration of Polluted Rivers, p. 196, August 1969, Office of Water Resources Research, Rutgers University

- W-19 Whipple, Wm. Jr., and S.L. Yu, "Aeration Systems for Large Navigable Rivers," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 97, No. 6, pp. 883-902, December 1971.
- W-20 Whipple, Wm. Jr., "BOD Mass Balance and Water Quality Standards," Water Resources Research, Vol. 6, No. 3, pp. 827-837, June 1970.
- W-21 Whipple, W. Jr., F.P. Coughlan, Jr., and S.L. Yu, "Instream Aerators for Polluted Rivers," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 96, No. 5, pp. 1153-1165, October 1970.
- W-22 White, A., and F.P. Gloyna, Radioactivity Transport in Water--Mathematical Simulation, p. 40, 1970, Texas University.
- W-23 White, W.A., and L.F. Tischler, "River Basin Quality Simulations," Proceedings of the 16th Annual Conference on Water for Texas, (Urban Water Resources Planning and Management), pp. 155-175, September 1971.
- W-24 White, W.A., L.F. Tischler, and T.A. Austin, "Water Quality Prediction Within an Interbasin Transfer System," Water Resources Bulletin, Vol. 8, No. 3, pp. 483-494, June 1972.
- W-25 Wiedeman, V.E., "Economic Aspects of Algae," Symposium on Hydrobiology, pp. 25-33, June 1970, Louisville University and Kentucky Department of Biology.
- W-26 Wilde, D.J., and C.S. Beightler, Foundations of Optimization, p. 480, 1967, Prentice-Hall, Inc., Englewood Cliffs, New Jersey.
- W-27 Wiley & Wilson, Consulting Engineers, Lynchburg, Virginia, Letter Reports on Water Supply, Harrisonburg, Virginia, April 1966.
- W-28 Wiley & Wilson, Consulting Engineers, Lynchburg, Virginia, Report on Water Supply Improvements for the City of Harrisonburg, Virginia, 1958.
- W-29 Wilson, C.W., and F.E. Beckett, Editors, Municipal Sewage Effluent for Irrigation, p. 169, July 1968, Proceedings of Symposium at Louisiana Polytechnic Institute.
- W-30 Wilson, D.L., Agricultural Incomes and the Impacts of Potential Development: Sevier River Basin, Utah, p. 21, May 1969, USDA, ERS, Forest Service and Soil Conservation Service.
- W-31 Wilson, L., T.B. Hutchings, and P. Shafer, "Arable Land Resources of Utah," Utah Resources Series 42, p. 37, 1968, Salt Lake City, Utah.
- W-32 Wilson, L., Emeritus Associate Professor, Soils and Biometeorology, Personal discussions during February 1972.

- W-33 Winiarski, L.D., and B.A. Tichenor, "Model of Natural Draft Cooling Tower Performance," Journal, Sanitary Engineering Div., ASCE Proceedings, Vol. 96, No. 4, pp. 927-943, August 1970.
- W-34 Wolff, J., F.P. Linaweaver, and J.C. Geyer, Water Use in Selected Commercial and Institutional Establishments in the Baltimore Metropolitan Area: A Report on the Commercial Water Use Research Project, June 1966, The Johns Hopkins University Press.
- W-35 Wollman, N., and Bonem, G., The Outlook for Water: Quality, Quantity and National Growth, 1971, Johns Hopkins Press for Resources for the Future, Baltimore, Md.
- W-36 Wolman, A., "Blame Nature for Impure Water," Civil Engineering, Vol. 40, No. 10, p. 162, 1970.
- W-37 Wolman, A., "Industrial Water Supply from Processed Sewage Treatment Plant Effluent at Baltimore, Md.," Water, Health and Society, pp. 74-83, 1969, Indiana University Press.
- W-38 Wolman, G., "The Nation's Rivers," Science, 174, 905, Nov 26, 1971, reprinted in Journal, Water Pollution Control Federation, Vol. 44, No. 5, pp. 715-737, May 1972.
- W-39 Wolman, A., "Water Supply and Environmental Health," Journal, AWWA, Vol. 62, No. 12, pp. 746-749, December 1970.
- W-40 Woodson, R.D. (Black & Veatch), "Cooling Towers for Large Steam-Electric Generating Units," Electric Power and Thermal Discharges, pp. 351-380, 1971, Gordon & Breach, New York.
- W-41 Woodward, D.R., Availability of Water in the United States with Special Reference to Industrial Needs by 1980, 1956-57, Industrial College of the Armed Forces, Washington, D.C.
- XYZ-1 Yevjevich, Vujica, An Objective Approach to Definitions and Investigations of Continental Hydrologic Droughts, Hydrology Paper No. 23, August 1967, Colorado State University, Fort Collins, Colorado.
- XYZ-2 York County, Pennsylvania Planning Commission, York County Economic Analysis, Volumes 1, 2, and 3.
- XYZ-3 York, Pennsylvania Chamber of Commerce, Industrial Committee, Manufacturers' Directory of York and York County, Pennsylvania, April 1970.
- XYZ-4 York Water Company, York, Pennsylvania, Annual Report of General Manager, 1962-1970.
- XYZ-5 Young, G.D., Tierney, G.F., and Selekof, J.S., "The Importance of Economic Factors in Urban Surface Water Supply Systems," Final Report, U.S. Department of the Interior, Office of Water Resources Research Report 1-960, June 1972, Water Resources Engineers, Inc., Springfield, Virginia.

- XYZ-6 Young, G.K., Taylor, R.S., and Hanks, J.J., "A Methodology for Assessing Economic Risk of Water Supply Shortages," Final Report, U.S. Army Corps of Engineers Institute for Water Resources, Contract OACW3-71-C-0046, IWR Report 72-6, May 1972, Water Resources Engineers, Inc., Springfield, Virginia.
- XYZ-7 Young, R.A., and J.D. Bredehoeft, "Digital Computer Simulation for Solving Management Problems of Conjunctive Groundwater and Surface Water Systems," Water Resources Research, Vol. 8, No. 3, pp. 533-556, June 1972.
- XYZ-8 Young, R.G., and D.J. Lisk, "Effect of Copper and Silver Ions on Algae," Journal, Water Pollution Control Federation, Vol. 44, No. 8, pp. 1643-1647, August 1972.
- XYZ-9 Zanoni, A.E., and R.J. Rutkowski, "Per Capita Loadings of Domestic Wastewater," Journal, Water Pollution Control Federation, Vol. 44, No. 9, pp. 1756-1762, September 1972.
- XYZ-10 Zillich, J.A., "Toxicity of Combined Chlorine Residuals to Fresh-water Fish," Journal, Water Pollution Control Federation, Vol. 44, No. 2, pp. 212-220, February 1972.
- XYZ-11 Zabler, L., Carey, George W., Greenberg, Michael R., and Hordon, Robert M., Benefits from Integrated Water Management in Urban Areas - The Case of the New York Metropolitan Region, April 1969, a report submitted to the Office of Water Resources Research, United States Department of the Interior.

INTEGRATING WATER QUALITY AND
WATER AND LAND RESOURCES PLANNING

BY

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July 1977

No. 77-26

REPORT OF WORK GROUP ON INSTITUTIONAL ARRANGEMENTS^{1/}

<u>Contents</u>	<u>Page</u>
Summary	98
Introduction	101
Water Quality Planning	103
Water Quality	104
Water and Related Land Development Planning	105
Federal View	109
Improving the Capacity of Federal Water Development Agencies in Water Quality	109
The Institutional Opportunity in Land Runoff Management	111
State View	113
New Roles for Basin Planning Agencies	115
Budgeting at the Regional Level	117
Cost-Sharing at the Regional Level	119
The Local View	120
Reinforcement of Local Government at the Local Regional Level	122
Public Participation	125

^{1/} From Workshop Report Integrating Water Quality and Water and Land Resources Planning, Proceedings from conference at Asilomar Conference Center, Pacific Grove, Cal., Jan. 11, 1976. Sponsored by the Universities Council on Water Resources and The Engineering Foundation, in cooperation with The U. S. Water Resources Council, Environmental Protection Agency, Dept. of Army - Corps of Engineers, Dept. of Interior and Dept. of Agriculture.

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SUMMARY

This work group explored the potential technical gains to be achieved by closer integration of water quality management with the management of the development of water and related land resources. The opportunities for achieving water quality goals (swimmable, fishable water) while carrying out water development (dams, channel changes, distribution works) are substantial. The opportunities for achieving water development goals (adequate supply, reduced risk, enhanced real national and regional incomes) while carrying out water quality management (treatment, collection, standard setting, enforcement) are substantial.

However, the gains from improved integration are often diffused, indirect, conjectural, and intangible. The costs of achieving integration are more concentrated, direct, specific and tangible. Overcoming tunnel vision takes resources of time, skill, patience and dedication -- always in short supply and always needed elsewhere. Present organizational arrangements, authorities, modes of consent building, and participant relationships are more separated and more specialized than such integration would require. Thus, while the social gains exist from which incentives to integrate could be fashioned, the prospect is for a difficult, torturous, evolutionary process of reform. There is no single, obvious gain to be realized for a small, well organized, well-placed group through political action. Rather the motivation for change must come because of modest efficiencies to be achieved here and there; because of the quiet rewards of proceeding in a more logical, professionally satisfying fashion; because we know we should respond to the environmentalists' lament that everything is related to everything else.

The system of government in the United States of America can be characterized in one way that is quite pertinent to this subject. It is a system where at least three levels of government are superimposed one over the other and each is given broad general responsibility for solving the nation's problems. Obviously constitutions and laws, the distribution of agency resources, the history of relationships and support, and the like, have given a pattern of varying involvement and capacity. The basis issue, then, is how should the capabilities at each of these governmental levels be improved in order to provide for the effective management of water resources and water quality problems. A key to improved capability is the relationship between and within levels of government in the exchanges of resources -- authority, expertise, funds, credit for success, etc.

At the Federal level the many agencies involved need to improve communication and coordination. Some of the tasks for the future suggest that existing capacities of one agency will be needed to achieve new advances in the mission of the other. A shifting of missions and more carefully linked programs can be foreseen. For example, regulatory skills will play a larger role in flood plain management, and technical assistance and cost sharing will play a larger role in control of pollutants from both urban and rural land.

The task at the federal level is not unlike that which faced the Federal agencies active in water and related land development in the years that preceded the passage of the Water Resources Planning Act of 1965. Single purpose agencies and projects gave way to the multiple purpose planning approach. Agencies were criticized for uncoordinated, competitive development of projects with too little regard for complementarities and basin interrelationships. Policies were rarely developed in a deliberate, multi-agency context and too many unforeseen consequences were seen as the result. Overlapping responsibility and duplication of effort, fragmentation and poor communication are still problems, obviously, but at least there are now mechanisms for dealing with them in the executive structure. Policy area by policy area, some coordination is resulting. More to the point, there is an arena, the Water Resources Council, where interagency differences can be debated and resolved when the President and the Congress choose to make use of it. This arena has the advantage of providing access for the states as well as the basin commissions.

At the state level correcting the imbalance of a large federally funded water quality capability as against a usually very modest water and land development planning capability must be addressed. Constitutionally, local governments depend upon the state's for authority and guidance. Too often capacity for that guidance to deal with the complexities of "everything being related to everything else" is lacking, while the inherent veto power of state government is held. Too often the result is delay, fear and frustration -- wasting the expensive, well intended efforts of federal and local participants. More to the point, the politics of water resources -- both quality and quantity aspects -- are changing, creating a vacuum probably best filled by the states. Environmental concerns have reduced the rewards and raised the costs of Congressional participation. Multi-interest accommodation has become more complex than can be dealt with by the agencies working with local constituents.

If the states are to become more effective in inter-relating water quality and water development interests, basin agencies will need to be strengthened. At present river basin commissions provide an arena for limited federal-state and interstate bargaining and accommodation. Coverage over the nation is incomplete. Compact commissions are not well integrated into the Water Resources Council's arrangements. Neither planning commissions nor broad purpose compact commissions have been established for some major basins. A wider role for existing commissions in budget formation and in program and project formulation is required; but this is not likely to come about until these planning commissions develop stronger clientele relationships. The integration of water quality and water/land development offers an important opportunity for such strengthening. In part, the opportunity is for the several states in a basin to unite in influencing the development of federal responses better designed to meet their needs. The Appalachian Regional Commission has been most successful in this for economic development. In part the opportunity is to coordinate at the basin system level.

Water and land development problems have simply outgrown the territorial jurisdictions of local governments. Urban regions and river basins are two of the interaction systems within which the external effects of independent actions are felt. Local governments have long exercised the controls necessary to deal with neighborhood systems and viewed with the boundaries of the neighborhood system in mind, they have been successful. Public services are effective and efficient. Controls reflect the public values expressed through the local political system. It is when one shifts his view from the neighborhood to the larger system that failure is apparent, but to blame the local governments for not developing the institutional arrangements needed is to confuse the issue. We suspect that an important missing ingredient is that public understanding (perhaps even the understanding by the experts and professionals) of the workings of these larger systems is lacking. The result is often misguided attempts to wrestle too much authority and function away from local governments. Too often the proposal is to put broad authority in the hands of a state or federal bureaucracy that lacks responsiveness to political representation and that lacks even the rudimentary capacity to be as comprehensive as a local governing body.

Thus the key may be to utilize both the interest-representation capacity of local governments and the technical expertise of the agencies of state and federal government through regional arrangements such as those currently being reinforced by EPA's "208" program, the Urban Studies Program of the Corps, the Total Water Management Program of Interior, the Resources Conservation and Development Projects of SCS, or the Coastal Zone Management Program of the Department of Commerce. The opportunity for coordination is apparent simply from this partial list of water programs attempting to operate at this level. We propose improving the coordination of the many planning activities at the sub-state regional level through a consolidated grant approach. This is not a new conclusion, but is uniquely re-affirmed by this work group.

Likewise, it is not new to stress that public participation, and educational efforts to stimulate participation, are important. We believe that the critical authority to deal with urban system and basin system effects of independent action will never be effectively exercised at those levels until education through participation produces the required understanding of these effects.

In our consideration of the institutional aspects of the integration of water quality planning with the development of water resources and related land a particular current case, dealing with land runoff, stood out as a vehicle for achieving changes in inter-agency and inter-governmental relationships. In most basins, we suspect, as much as half of the pollutants in the water come from sources that are not amenable to end-of-the-pipe treatment. In some cases the proportion may be as high as 80 percent. If this is true, attempting to control the quality of our waters by higher and higher levels of treatment at the end of the pipe will be less and less

cost effective. But our cost sharing and regulatory arrangements are almost wholly concentrated on sewers and sewage treatment works, on municipal sanitation systems and industrial dischargers.

Dealing with land runoff from rural land suggests engaging the existing network of county level agencies serviced by the U.S. Department of Agriculture. Cost sharing and technical assistance programs already exist that, with modification, could add a pollution control objective to the existing land and water development objective. Tentative steps in this direction have been made but not within the context of the coordinating mechanisms at either the federal or basin (i.e., state) level. At the urban region level, e.g., through "208" planning, the opportunity is particularly promising to engage the U.S. Department of Agriculture (USDA) in the problems of construction sites as well as the remaining open country.

Runoff from the urbanized areas themselves has long been a recognized problem. Interestingly combined sewers were long the focus as a hold-over from the human health orientation of pollution control. Treating the runoff, if considered as domestic sewage, promises to be expensive. In many communities that same runoff is also a flooding problem from time to time. Is there opportunity for the Corps of Engineers here? If so, what is the extent of it? Existing needs' studies do not provide sufficient estimates of the opportunity for realistic approaches to this problem. The impression is clear that little consideration has been given to the joint solution of urban interior drainage and pollution from urban land runoff. Shouldn't our mechanisms for policy coordination explore such opportunities? If planning were more integrated, would such questions be resolved more effectively? We believe they would.

INTRODUCTION

Institutions can be defined in the context of water resource development and water quality improvement by putting emphasis on the organizations whose behavior relates to water. The structure of these organizations -- their leadership, resources, authority, image and relationships to other organizations -- is related to their behavior. Visualizing the cast of characters in the public decision-making process, identifying their stakes and resources available to influence the many veto points in consent building, helps to arrive at suggestions for change that will provide different outputs from the system. Looking ahead in water development and water quality, the need for different outputs is apparent. It is unlikely that change in the mix of water outputs can come about without organization restructuring. It is an article of faith that greater governmental effectiveness can be achieved if this restructuring comes about in response to systematic analysis rather than mindless evolution.

Yet it is clear that institutional reform rarely comes about through large changes. Rather change comes about in many small steps that respond to new needs and values, to new perceptions and understanding. The challenge to this work group was to visualize long range goals for overall water resource management and identify the next increments of institutional reform that can realistically be expected to be placed upon the agenda for consideration by those who must agree to any change. With the resources of time and expertise available, an in-depth analysis is not possible. Luckily it is not needed. If we can stimulate others to think in new directions, we will have achieved enough. Debate between the many participants in public policy development will sharpen and refine the analysis in ways that are probably not even predictable by the work group or the reader of this report.

Conventional wisdom in public administration goes back to the concepts of Woodrow Wilson, perhaps the only political scientist who "made it". The fragmentation and overlapping of responsibility and authority would, in the conventional model, be viewed with alarm. The prescription that follows would be to achieve consolidation and centralization. The reasoning would be that a well articulated, scientifically designed hierarchy, staffed with trained civil servants, separated sharply from the political policy-setting structure of government could more effectively respond to the public interest.

Of course, we now understand many of the limitations and difficulties in applying this model. Can we really expect to restructure American government in response to the logic of water resource management? The overlap between function and objectives of government, the diversity of needs, perception and priorities, the widely varying organizational circumstances of the parts of our water systems suggest that simply "neatening up" the organizational structure will not be sufficient. The advantages of multiple responsibility in entrepreneurship and innovation, legitimate interest representation, the limits of economies of scale from large organizations, the data and theoretical limits on truly being comprehensive, and similar problems suggest that we should proceed in a more eclectic and less-structured way. The logic of the tasks to be done is a place to start.

Water development and water quality management have a history of particular means employed to deal with limited aspects of selected problems. Water development has emphasized the construction of dams, channel improvements and other public works that manage the supply of water for irrigation, municipal and industrial use, flood control, power, recreation and the like. Water quality management has focused upon treatment of waste, collected together at one point. Public funds have been invested again in public works, recently at a massive scale. Regulatory arrangements have been developed to encourage private response to waste treatment, focusing on industrial activities that have end-of-the-pipe potential.

It is clear that the future of both water quantity and water quality will be somewhat different than the past. Both will have to seek more non-capital intensive non-structural solutions. Demand management strategies, land use measures and the like will become more demanding of institutional capacity. Instead of a federal dam to provide flood protection, that protection may be provided by incentives and regulations to clear the flood plain and provide flood proofing, early warnings, as well as structures, through a complex of interlocking federal, state and local actions. Added to federal and state cost sharing for treatment plants and a complex federal-state regulatory system we can expect incentives and regulations to manage the location of industry, to encourage silt control at construction sites, to require land treatment practices to halt the flow of nutrients and pesticides from the land. Again federal, state and local actions will be complex and intertwined. Indeed, it could be argued that decision-making capacity will be the limiting factor in responding to a public demand for greater effectiveness in government management of the water resource.

This work group suspects that the greatest achievement of increased integration and coordination of water quality and water development will come from expanded institutional capacity, and the capacity to make decisions that will result. Note, for example, that non-structural measures for water development will require application of enforcement and regulatory capacities that are currently more developed in the water quality area at every level of government. On the investment side, progress in water quality will require moving away from the current fixation with sewers. In most cases, less than half of the pollution problem can be dealt with by a treatment-plant-centered approach. And the costs of those last few increments of treatment are spectacularly high. Approaches that emphasize technical assistance and cost sharing for land use practices should come into their own in quality management rather than their present orientation to water development. Again, existing institutional capacity can be utilized through more effective integration. Similarly, stormwater runoff involves drainage and flood control problems that can be more effectively dealt with if water quality aspects are considered at the same time. Invoking the multiple purpose approach will tend to generate more support for all problems and to justify the considerable expense involved.

WATER QUALITY PLANNING

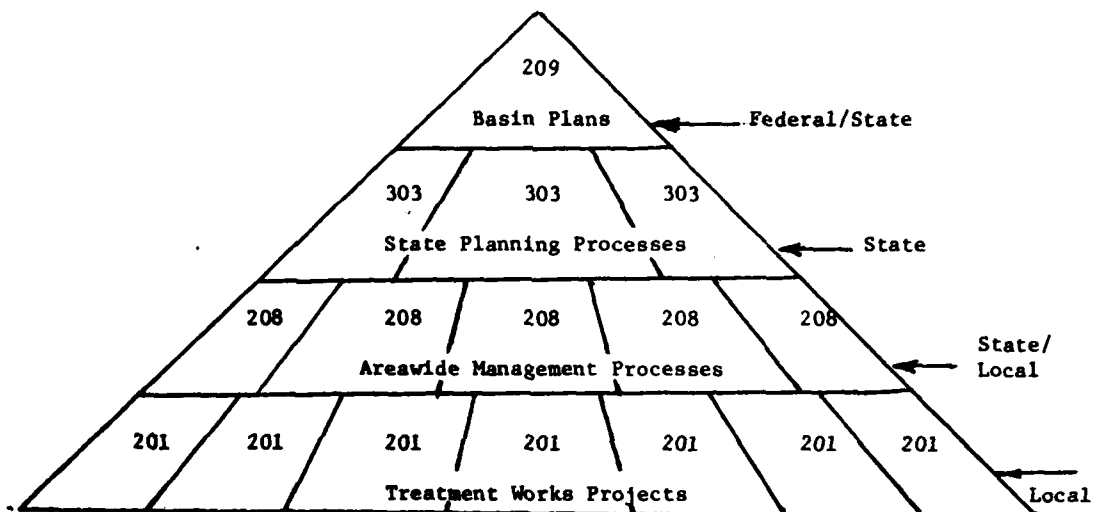
At the current time there are two major pieces of federal legislation which provide a structure and direction for the institutional arrangements for managing water quality and water resource issues: the Federal Water Pollution Control Act (P.L. 92-500), and the Water Resources Planning Act (P.L. 89-80).

WATER QUALITY

The Federal Water Pollution Control Act Amendments of 1972 (P.L. 92-500) has four key provisions which provide for the integrated management of water pollution control problems: Sections 201, 208, 303, and 209.

Section 209 is a vehicle for the integration of water resources and water quality issues at the river basin commission level. Section 303 provides for the development of statewide planning processes for the development and implementation of effluent limitations and water quality standard compliance schedules, and the development of priorities for the construction of waste treatment works. Section 208 provides for the construction of continuous areawide waste treatment management processes at the local and regional levels. Section 201 provides for the development and implementation of specific treatment works projects. Therefore, 201 provides for the smallest level of detail, the actual project, while 209 plans represent the macro level of integrated water resources and water quality management. The conceptual relationship between these authorities is illustrated by the pyramid in Exhibit 1.

Exhibit 1. Conceptual Relationship Between Planning Authority Sections in Public Law 92-500



A summary of the specific responsibilities established by statute for the three levels of government (federal, state, local, regional) for water quality management is illustrated in the attached table. Generally, the major focus of implementation activity for each water quality management activity is as follows:

	<u>Section 209</u>	Integrated water resources/water quality planning:
Federal/State		
	<u>Section 303</u>	State water quality planning: State
	<u>Section 208</u>	Areawide waste treatment management
Local	<u>Section 201</u>	Waste treatment works implementation: Regional/

In actual fact this conceptual relationship has not as yet been fully implemented. Plans for actual treatment works were well underway and institutional arrangements fully operative when the legislation was passed. Likewise, state level planning capacity for water quality was in hand in many states. While some basin studies that took a stab at integrating water quality and water development are available, the degree of integration is still not extensive. Areawide planning in the "208" process is just getting started against a background of treatment plant plans usually completed and a system of standards and guidelines for long-term industrial water permits in hand.

WATER AND RELATED LAND DEVELOPMENT PLANNING

P.L. 89-80 established the Water Resources Council as the coordinator and managing entity for water resources planning at the Federal level. Through the mechanism of joint plans developed through basin commissions with agency and state participation the advantages of integration have been sought. Three planning levels are recognized from the broadest to the most detailed.

"Level A" framework studies and assessments are seen as evaluation of needs and desires for "the conservation, development and utilization of water and related land resources." Typically a region of several river basins is examined at a single time or a nationwide assessment by major region is accomplished. Subregions with more specific problems are identified to guide future study. Seven Level A studies have been completed on specific regions and five are ongoing. The first national assessment was produced in 1968 and a second is in process. Twenty-one regional reports are expected. Priorities will be developed for the various problems identified. Completion is expected in 1977.

"Level B" regional or river basin plans are to solve complex and long range problems. A broad range of alternative measures are considered and short and medium term action plans suggested. They are the current version of a mode of basin planning that extends back to the 1920's and earlier when the Bureau of Reclamation and the Corps of Engineers were charged by the Congress to develop broad developmental

**WATER QUALITY MANAGEMENT
AS PROVIDED FOR BY THE FEDERAL WATER POLLUTION CONTROL ACT (P.L. 92-100)**

Government Level	Section 209 Basin Plans	Section 303 State Plans	Section 208 Regional Management	Section 201 Project Implementation
<u>Federal</u>	<p>Federal grants for plans development</p> <p>Plans to be integrated analysis of water quality and water resources issues on a basin or sub-basin level</p> <p>Plans to focus on water quality and water resources matters in designated section 208 areas</p>	<p>Federal grants to States</p> <p>Approval of State planning process</p>	<p>Federal grants to States and designated local agencies</p> <p>Approve certified 208 plans</p>	<p>Federal grants for treatment works</p> <p>Approve local grant applications:</p> <ul style="list-style-type: none"> - project included in applicable 208 plan - project in conformity with State 303 plan - project entitled to priority re: Section 303 plan - Federal requirements complied with re: project
<u>State</u>	<p>All plans to be completed by January 1980</p> <p>Substantial State participation via representation on River Basin Commissions</p>	<p>Develop and implement statewide planning process to result in plans for all navigable waters of State</p> <p>Plan to include:</p> <ul style="list-style-type: none"> - effluent limitations, water quality limitations, and compliance schedules; total maximum daily load for pollutants; - inventory and ranking in order of priority of needs for construction of treatment works - incorporation of all elements of applicable 208 areawide waste treatment management plans 	<p>Designate 208 local/regional areas and organizations</p> <p>Certify each areawide plan as being consistent w/applicable 209 and 303 plans</p> <p>Areawide waste treatment management planning for balance-of-State non-designated area</p> <p>Implementation of 208 plans for non-designated areas</p> <p>Statewide regulatory program for non-point sewer controls</p>	<p>Certify project priority</p> <p>Approve local grant applications</p> <p>Contribute to local share of funds</p>
<u>Local/Regional</u>	<p>Little or no local/regional involvement in plan development</p>	<p>Limited local involvement in plan and process development</p>	<p>Areawide waste treatment management planning for designated 208 areas</p> <p>Implementation of 208 plan for designated areas</p>	<p>Develop grant application</p> <p>Project level decisions</p> <p>Local share of funds</p>

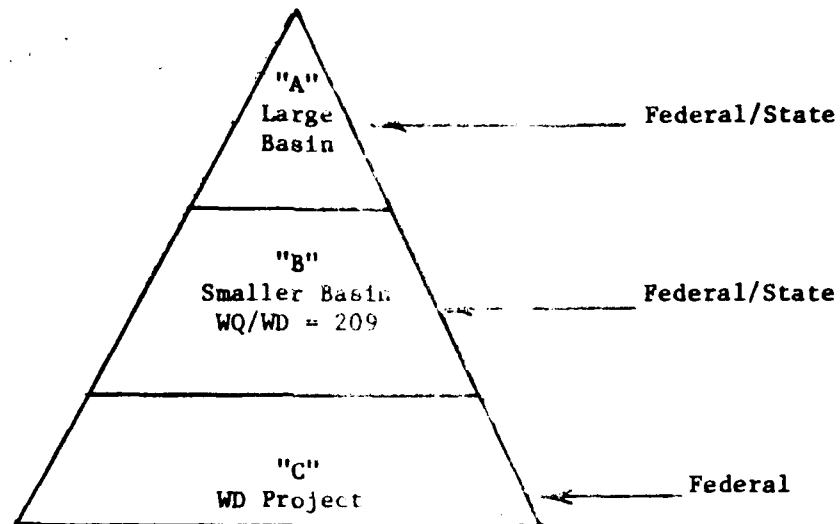
studies that reviewed project opportunities at the reconnaissance level. Various forms of inter-agency, and more recently state cooperation have been tried out and are still in use where Title II river basin planning commissions or the equivalent are not yet organized. Particularly pertinent to this level of planning are the Council's "Principles and Standards" for planning and evaluation. These are an approach designed to stimulate the identification of alternative patterns of measures through the consideration of multiple objectives -- currently national economic development and environmental quality. Impacts on regional development and other social well-being factors are considered but do not serve as plan formulation objectives at this time. Twelve Level B studies are in various stages of completion, while 15 have been completed.

"Level C" studies -- project evaluations -- are visualized as flowing from the A and B analyses -- where the interactions in the region are accounted for and regional priorities expressed. In fact, much like the water quality planning experience, Level A and B planning is just beginning to have impact on project planning. Project politics, and the much longer history of project level activity, have prevented faster assimilation of comprehensive planning into the system. A full analysis of this phenomenon equally applicable to water quality or water development projects is beyond the scope of this discussion. Suffice it to say that elected officials and concerned citizens find it much easier to relate to tangible and immediate problems and their short range solutions than to long range, complex and conjectural planning studies dominated by professionals in the agencies. Thus, like comprehensive planners in virtually every area of public concern the water planners have a very modest record of impacting day-to-day decision-making.

Level C planning is managed directly by an action agency and is usually a routine part of its process of investment management. In the case of the Corps of Engineers and the Bureau of Reclamation, Level C planning leads to recommendations to the Congress for individual project authorization and funding. In the case of the Soil Conservation Service and TVA the planning leads to an internal authorization of projects under formal and informal Congressional guidance. The Water Resources Council "Principles and Standards" apply to Level C planning with substantial modification to conform to Congressional guidance to each agency. The conceptual relationship of Level A, B and C studies are illustrated in Exhibit 2.

This is not to suggest that all planning carried out by the federal agencies concerned with the development of water and related land neatly falls into the Water Resources Council's classification system. The Army Corps' of Engineers Northeast Water Supply Study, the Bureau of Reclamation, West Wide Study, the Soil Conservation Service (SCS), Great Plains Conservation Program, Tennessee Valley Authority general development studies, studies to implement the flood insurance program, state water planning studies, and the like, cross the boundaries. Of particular interest to this analysis are the Total Water Management Studies of the Department of the Interior, the Corps' Urban Studies Program, the SCS Resource Conservation and Development Projects, Economic Development Agency's (EDA) county and regional development

**Exhibit 2. Conceptual Relationship of Levels of
Planning for Water Resources and Related Land by the
Federal Agencies Under Coordination by the Water Resources Council**



efforts, the Department of Commerce "Title V(a)" regional commissions and Coastal Zone Management Studies. Each of these is focused on either an urban region, a grouping of counties or some other region at the sub-state level. Each has a significant relationship to the management of water and land resources and represents a level at which inter-agency and inter-interest coordination and accommodation is important, directly parallel to the "208" level in water quality planning. In each case there is an orientation to action programs and closer cooperation and greater dependence on implementation by local government than is typically the case with the usual Level C planning by federal agencies.

To sum up, the basic statutory thrusts of these two programs are different:

- a major goal of P.L. 92-500 is to eliminate discharge of pollutants into navigable waters and provide for the protection and propagation of fish and wildlife, and provide for recreation throughout the United States by 1983;
- a major goal of P.L. 89-80 is to enhance economic development and the quality of the environment through the optimization of water and land resources.

Each water resources project must pass muster as a vehicle for enhancing multiple economic and resources objectives before it is a likely candidate for construction, while there is the implicit assumption that developing treatment works projects will, by definition, be a contribution to the social good and hence needs no further justification in terms of economies or land and water resource usage.

FEDERAL VIEW

At the federal level there is well-developed expertise in planning and implementing water resource solutions, while the federal capability in water quality is well developed in terms of setting effluent regulations and serving as a source of funds and guidance for the development of planning, management, and implementation capabilities at the state and local levels. These strengths reflect the basic thrust of the enabling legislation.

The Water Resources Planning Act focuses on maximum economic development of water and land resources, while the Federal Water Pollution Control Act (FWPCA) is regulatory and focuses on the specific objective of water quality. In addition, the FWPCA goes beyond functional planning and provides a vehicle for the development of the institutional arrangements necessary to implement the plan once developed.

The complete integration of water quality planning into water and land resources planning would include applying the "Principles and Standards" to project formulation and evaluation. This action would subvert the regulatory intent of P.L. 92-500. However, integration of certain elements of water quality planning, e.g., non-point source pollution, may be a desirable objective. However, full coordination of water quality planning with water and land resource planning is a necessary prerequisite to optimizing the use of federal dollars and resources to effect a change locally. Specifically, coordination should be improved at the federal level between the Environmental Protection Agency, which has the primary responsibility for implementing the FWPCA, the Civil Works divisions of the U.S. Army Corps of Engineers, which has a primary responsibility for water resources development, and the Soil Conservation Service, which has a potential institutional capacity through its technical assistance and cost sharing to facilitate water quality management at a local level, particularly on rural land.

IMPROVING THE CAPACITY OF FEDERAL WATER DEVELOPMENT AGENCIES IN WATER QUALITY

Consider the position of the typical water development (WD) agency (Corps, Bureau of Reclamation, SCS or TVA) as it tries to relate its project plan to water quality (WQ) planning and management activities of the Federal, state, and local organizations involved. Typically, the main elements of the plan are limited to dams and channel work. These

can raise water quality problems such as temperature changes, nutrient traps, low flow changes and return flows from irrigation and other sources.

The Environmental Protection Agency comments on the Environmental Impact Statement (EIS) are a major point of contact. They have potential to hurt the process of building support for the WD project; and as presently carried out, there is not much hope in the WD agency that the review will actually help in the current process. The best that can be expected is a neutral result. Thus in the environmental quality (EQ) portion of the WD plan formulation as required by the Principles and Standards, the WD agency will try to anticipate the EPA concerns in the EIS process. EPA, and related WQ agencies, will probably not participate directly in the EQ plan formation and the WD agency will use its own sources or expertise, which are integrated by function but not by agency. Besides anticipation of EPA and other environmental reactions, the water development agency will also consider what would be accepted as adequate environmental accommodation by other participants in the decision process (e.g., governors, interest groups, Congressional staff, local officials). This may be quite different than the EPA view, but if accurately assessed by the water development agency the bargaining ability of the environmental quality interest is reduced. Combine a gross dissatisfaction by environmental quality interests with the degree of accommodation they have won and the late timing of the Environmental Impact Statement process in the planning process and the seeds of stalemate and wasted, scarce, decision capacity have been sown.

EPA and related groups gain considerable advantage from working through the Environmental Impact Statement process rather than the environmental quality planning process under the Water Resources Council "Principles and Standards." In either case they have resources that include a recognized expertise and a recognized watchdog role; but the Environmental Impact Statement process is recognized more broadly as a legitimate focus for them and, unlike other participants EPA has a statutory role of issuing guidelines (and, by implication, judging whether they have been met). EPA does not have that resource or anything like it in the environmental quality plan formulation process, and the Environmental Impact Statement process calls for less commitment of personnel.

A second interface is with the application of water quality standards to the results of a water development project. While this is a state prerogative, the state's role is reinforced by EPA and a joint position is worked out. The state water development agency is quite apt to have a different position on the project and, while more likely to be a natural ally to the federal water development agency, it still offers some capacity to mediate differences.

Finally there is little that the federal water development agencies have to trade to accommodate EPA and other environmental quality interests in an indirect or mitigation fashion. Low flow

augmentation cannot be used directly to gain water quality benefits under most circumstances. When achieved through other purposes (e.g., municipal and industrial or power), other problems complicate the trade-off. Yet often development will be violating the non-degradation principle in water quality, and accommodation is to be desired. Flexibility may be lacking to bargain for an accommodation where energy or development or poverty interests are overwhelming.

A question is how can water development agencies more effectively deal with water quality outputs through the planning process?

Strengthening of the river basin commission as a participant in water quality accommodation in project planning could come about from a more effective role in broader planning (209 and level B). The present commissions aren't providing the potential arena for effective bargaining because neither the WQ nor the WD agencies have incentive to take them that seriously. Almost any of the steps to strengthen these commissions, discussed elsewhere, would help; but in particular increasing their environmental evaluation role and a role in cost sharing for special environmental projects would be particularly desirable.

The construction agencies need more scope to achieve WQ outputs. This should improve the bargaining and might encourage EPA and other WQ agency participation (state and local) in EQ plan formation. It also would prepare for the eventual national shift in emphasis from the existing point-source fixation. Each WD agency has a substantial opportunity to provide important WQ outputs. The USDA has an organizational structure in the Soil Conservation Service (SCS), Agricultural Stabilization and Conservation Service (ASCS), Farmers Home Administration (FHA), and Cooperative Extension capabilities to deal with a large part of the land run off pollution problem. The Corps of Engineers could offer direct construction and operational services for acid mine drainage elimination in over 20 states. Engineering services are also a potential for irrigation return flows, natural salinity sources and other similar needs from the Bureau of Reclamation as well as SCS and the Corps.

THE INSTITUTIONAL OPPORTUNITY IN LAND RUNOFF MANAGEMENT

Will the nation develop a new set of institutional arrangements to control non-point sources of pollution? Or will we adopt an existing network of intergovernmental arrangements to the new task? Few seem to disagree that a major part of the existing pollution loading in the nation's waters comes from someplace other than an industrial or municipal discharge pipe. Since no agency systematically collects data that allows a firm estimate, expert opinion based upon fragmentary information must suffice. Presentations to the task group set the range as 50 to 80 percent of the nutrients, oxygen demanding substances, silt, other dissolved and undissolved solids, exotic chemicals, and the like were not amenable to environmental end-of-the-pipe treatment.

However, a glance at the federal and state water quality programs would not suggest that this was the case. Virtually all of the in-place regulatory activity and financial incentives are directed toward higher and higher rates of removal from a smaller and smaller proportion of the problem. Section 208 planning was intended by the Congress to address this problem of cost effectiveness. Some non-point sources have not been well identified and it was expected by some that the urban region studies would both identify the extent of the problem of unrecorded pollutants and devise regulatory approaches.

Several problems are suspected although only when the "208" plans are in will it be possible to speak with any authority. First, the short study period raises doubts about the ability to identify with any great precision previously unidentified sources of pollution. Second, it is not clear that the expertise needed to gauge the technical options for corrective measures has been adequately involved. Indeed, it is quite certain that knowledge is not sufficient to relate particular corrective measures to observable changes in pollutant loads. Third, the result may be that few creditable control programs, and the requisite institutional changes, will be forthcoming. Finally, the very low level of public understanding of the problem will limit the support for those institutional arrangements unless they are facilitated by a program of technical assistance, inter-governmental reinforcement of regulatory devices and cost-sharing comparable to that now available to communities and industrial point dischargers. If the "208" experiment is viewed as a chance to surface some suggestions for what to do, in the face of no clear-cut prescriptions elsewhere, and as an educational and limited information-building opportunity, its potential in non-point pollution control may be correctly indicated.

Building a non-point management program on existing institutional arrangements has appeal. Iowa has gone a long way towards this. New York and some other states have had legislation under consideration. Essentially the concept is to utilize the existing water quality stream classification approaches and agencies to set standards; and where the degradation has dropped below these points, to call upon the existing organization apparatus for erosion control to come into play to encourage practices which will reduce the runoff from the land. Essentially the same technology employed to hold soil (e.g., silt) on the land to maintain agricultural productivity is seen as having the potential to hold other pollutants back as well. How precisely it is possible to prescribe these practices and be assured that cost-effectiveness is achieved has been questioned. But remember many of these practices have been advocated well before the current concerns for quality.

Research is necessary on two counts. First, it is intrinsically important that prescriptions for measures not be wasteful. Second, it is not likely that we will make rapid progress in the institutional arrangements required until the measures they are to

implement are well understood. The investment to go with it by millions of separate property owners -- which is what some envision as being required -- is just not going to happen unless there is a solid underpinning of understanding and support. The institutional challenge may exceed that posed by the end-of-the-pipe problem.

Luckily, it will be possible to experiment in a variety of ways and take advantage of those motivations in addition to water quality management. The Soil Conservation Service with its technical assistance capability at the county level through county Soil and Water Conservation Districts and the supportive USDA and state programs (funding through ASCS, research and education directly and through the Land Grant University systems) provide a potential delivery system. However, this system is too often seen as a farm income maintenance and/or food and fibre output stimulation system. Is the apparent conflict of interest between the environmental quality objective and the national economic development fatal? It need not be a detriment if the inter-agency and inter-governmental relationships are carefully worked out. It is this need which suggests that these arrangements would be best worked out as a feature of achieving closer integration of water quality and water development planning.

While this discussion has stressed the use of rural oriented water and related land development arrangements for the achievement of water quality management, a similar case can be made for utilizing the skills of the Corps of Engineers. Linking internal drainage of urban areas with the problem of pollution from stormwater runoff is a challenge which some of the Corps' urban studies have addressed. Over the years the Corps has not developed an extensive role in the localized aspects of urban drainage. These have been viewed as problems for municipal government. As long as the context was water development and flood control this was reasonable. Is it now? Again, inter-governmental and inter-agency arrangements need to be carefully worked out suggesting, again, an experimental approach in the context of greater integration of water quality and water development planning.

STATE VIEW

There is a wide variance in the type and extent of responsibilities exercised by state level water resources and water pollution control agencies. There is also wide variance in the relative capacities of the respective agencies. In water pollution control, state agencies are the primary planning and program administration components of the inter-governmental system. State level responsibilities in water pollution control are growing with the addition of state level 208 (see the Natural Resources Defense Council vs. Train decision) and overall planning oversight and coordination authority. The prospect of a primary state role in the administration of the

construction grants program (Certification program -- Section 8 of HR 9560) and the increased transition from federal to state authority over the permit program are likely to further strengthen the state position.

For substantial parts of the water resources area, planning and development are performed primarily by federal agencies. Municipal and industrial water supply and urban drainage are the major exceptions. In general, the picture is one of the state emphasis in water pollution control (despite increased federal involvement in terms of policy and guidance) and federal emphasis in water resources. Though state responsibility in the water resources area may increase, there is no current indication of a growth comparable to that being experienced by state water pollution control agencies. Though federal agency roles in water pollution control may expand, there is no current indication of a growth comparable to that of the federal agencies in water resources development.

There are a variety of mechanisms through which the states could be encouraged to better coordinate and integrate their water quality capabilities with their water resource development capabilities. For example:

- Encourage state water resource agencies to relate to their water pollution counterparts at the state level, rather than to EPA, in regard to information exchange, sharing perspectives on common problems, etc. EPA can assist in fostering improved relations.

- Develop mechanisms to facilitate closer relationships between state and federal water resource agencies, comparable to some extent to those obtaining in water pollution control (both cooperative and creatively antagonistic relationships would be in order).

- Develop mechanisms to build upon the coordinative and integrative intent expressed in EPA's new state planning regulations, with application to a wide range of resource and developmental planning and in particular to state-level relationships on Level B studies.

- Encourage, where appropriate, and fund, if possible, the growth of state comprehensive planning office responsibility for coordinating water quality and water resources planning. The development of standardized data collection, methodologies, and sections (land use, economic, demographic) could be a major component of such increased responsibility.

Begin to plan for a definition of responsibility and a synchronization of efforts in regard to non-point source control activities at the state level.

Assuming and, if possible, encouraging an increased local capability in exercising both water pollution control and water resources management responsibilities, develop an understanding of how the state role may be altered as a consequence and how state responsibilities may be exercised, for example, with respect to handling cross-jurisdictional disputes and interrelationships at local levels.

Develop an improved understanding of the attitudinal context in which increased state level coordination must be grounded. Available (and very modest) evidence indicates a strong view on the part of state water pollution control officials that water pollution control and water resources management should be integrated functional activities. A much more detailed and comprehensive understanding of the attitudinal dimension, on both sides, would be useful. Perhaps this is more appropriately regarded as a research question.

In addition, the existing institutional arrangements of river basin commissions should be buttressed

NEW ROLES FOR BASIN PLANNING AGENCIES

Environmental and other indirect impacts, however imperfect our methodology, are now an accepted part of formal project evaluation. Just to meet Environmental Impact Statement requirements, it is necessary to open the analysis of the project to critiques from those interested in such values. Formal multiple objective evaluation procedures proposed by the Water Resources Council may be modified as a result of current reviews. But it is unlikely that some of the elements that are new to the evaluation, such as in some elements of the social well-being account, will be lost.

Regional development is no longer the avoidable, simple issue it once was. At least since Pennsylvania objected to Ohio Congressman Mike Kerwin's proposal to link the Ohio River with Lake Erie, some interregional impacts have had political interest. As important is the ambivalence that now exists in many parts of the country about whether regional development is even desirable. Indeed, Oregon's experience seems to say a posture of avoiding development is a good way to attract it. And of course, there is still strong interest in dealing with disadvantaged groups who often have a particular geographic distribution. In addition, water projects now have many other Federal programs that compete for local activist support, and that frequently are seen as less conflict producing.

The point is that project benefit-cost analysis has major weaknesses from both a political and technical level that might be corrected somewhat through the participation of an analytical group at the regional level. When analysis is done project-by-project, there are many things that seem to suffer. The cumulative effects of a series of projects is harder to establish and usually ignored. Reaping the technical advantages of hydrologically linking projects becomes difficult -- especially between projects of different agencies. More difficult is the linking of water programs to other development actions. The show case character of the few projects where this was done in the Appalachian water plan make that point. Perhaps they would do better in a second plan. But even the evaluation of environmental, social and economic system effects is difficult. Also to be considered is the tendency for "ad hocery", i.e., consideration of cost and output effects, beyond the most basic, only when it is to the advantage of the moment.

But perhaps the greatest need that might be served by stronger regional arrangements is the interaction between the technical and political aspects of system evaluation. Individual water agencies are hard pressed to develop the expertise to perform creditable environmental and social analysis or even analysis of the indirect economic effects. Part of the problem is that they, as specialized organizations, find it difficult to see the inter-relations among water projects and other public actions or even among water projects themselves if they cross agency lines. Part of the problem is that with the increased potential for conflict in water projects, it is rational to start more planning studies and put less into each; yet evaluation of environmental, social and regional systems is most demanding of analytical capacity, calling for more resources, not less. Part of the problem is that we have not yet developed highly accepted measurement and evaluation methodology to show good cause and effect between projects and all the called for aspects of environmental, social and regional development systems, at least not comparable to that which is used in the engineering and national economic evaluation. The result is that the agency -- seen as an advocate for its proposal -- suffers from general suspicion of its analytics.

A basin agency with capacity to evaluate projects at the system level could at least critique and finally bless the analytics of the agencies. But if the scale economies of system analysis in environmental, social and regional development are as great as they seem at this time, it may be advantageous for the basin agency to actually do some of the project analysis and provide formulation guidelines for project plans. It should be remembered, however, that what is needed is not just more analytical competence judged by the experts, but also linkage to political capacity as judged by those affected by the projects. It is here that the interaction of cost sharing and analytical role is important.

The existing Water Resources Council may need to be restructured somewhat to give a broader representation and to more effectively participate in the budget process. This might be recognized by placing more agencies under the effective coordination of the Water Resources Council. This extends beyond the need to integrate water quality programs more effectively. Coverage by the "Principles and Standards" for planning and evaluation is a case in point. To date only a small part of the Federal investment is covered. Coordination of agency basin planning budgets and schedules is another.

Perhaps the organization of the Title II basin planning commissions suggests several alternatives for the structure of the Council itself. Note that the federal chairman personally oversees much of the basin commission staff activity. His only duty is as commission chairman, and thus he avoids the existing suspicion at the federal level that the Council may favor the agency headed by the chairman.

Note also that the Title II Commission is made up of federal agencies as well as state representatives. In a planning context this should have advantages. But in other roles the general governmental representation of the typical compact commission may be preferable. Should overlapping arrangements be recognized now as worthwhile to meet different needs? For example, should existing Compact Commissions be authorized to form the nucleus of a Title II Commission? The same people could wear different hats, calling meetings of different representatives depending upon whether they were meeting as a Title II commission or a compact commission.

At the regional level, consideration also should be given to improving the access and participation of localities, citizen groups, metropolitan areas and other regional entities such as those for urban planning, regional development and coastal zone management.

Congressional committees prior to reviewing the authority, guidelines, and appropriation for individual water programs should direct the basin commissions to prepare reports and offer testimony on priorities from the basin point of view. An independent chairman of the Water Resources Council, more formal recognition of the coordinative role of the Assistant Secretaries in the several departments, and expanded emphasis on the participation of the governors of the states could go far towards identifying a commission as an independent viewpoint and a focus for coordination.

BUDGETING AT THE REGIONAL LEVEL

Perhaps the most important decision network is that associated with structuring and agreeing upon public budgets. Most general governments are under pressure to change the process by which priorities are set and needs evaluated. In most cases the pressure is to find

ways to make more meaningful comparisons, if not between every objective and means, at least within larger categories than is presently possible with the highly fragmented approach of most budgeting processes. (Wildavsky, 1974) In proposals for such reforms enhancing the role of the region could make procedural and political sense. On the one hand, the region may be a level where trade-offs can be more accurately identified and related to the problems of interdependency and jointness. On the other hand, it may also be easier to identify the balance and accommodation needed to assure support. The result could be much more effective use of public funds.

For example, most programs are now balanced by region within quite narrow agency lines. Each agency tries to have a program in every state about comparable to the political significance of that state. But some agency programs are more important to some regions than others. Allowing more imbalance by agency in exchange for more balance over the whole water program should allow for greater efficiency and perhaps easier agreement. But this suggests a mechanism for accomplishment that has the trust and confidence of the agencies and the Congress.

Also seeing a single program broken into regional components has some potential for increasing program effectiveness. It is commonplace to point out that broad national budget components are relatively fixed from year to year. Yet there is a tendency to treat individual projects as if they posed no opportunity cost in the budget. Perhaps regionalization of programs would suggest that sizing a project at \$16 million, where an \$8 million solution was almost as good a problem solution, was doing the region out of a second project.

The Corps now prepares a five-year budget by region. Should the other agencies do likewise? Shouldn't all planning budgets, as well as construction, be put on a regional basis? Isn't regional monitoring and assessment of environmental quality (EQ) regional development (RD) and social well-being (SWB) factors closely akin to the planning input? The Water Resources Council should continue to shift the concept for level B planning toward greater usefulness at the project level -- shorter time horizon, more issue and conflict orientation. Congress has heard from basin groups regularly -- but perhaps it should ask them to play a more obvious role in their budget process. Of course, giving basin commissions a cost-sharing role and providing for expanded input into the EQ, RD, and SWB aspects of project planning, as well as funding, would put them into the budget process. At very least, representatives of basin arrangements should comment on the size and shape of both the construction and planning budgets in their region. It would have to be established and recognized that they represented a point of view independent of the President's and thus not subject to clearance by the Office of Management and Budget. Emphasizing the state representation involved could do this.

Alternative channels for federal aid, as complements to existing arrangements for direct project fiscal participation, should be considered. It is doubtful that direct shares can be reduced otherwise. But if more significant indirect cost sharing through clearer labeling of the funds could be used to more precisely key assistance to specific national objectives -- for example, the economic development of disadvantaged regions and minority groups, enhancement or mitigation of environmental values. Such keying could be viewed as a way to induce or make more effective participation in the decision process of particular groups or points of view, those that have access to the channels chosen. Revenue sharing as an alternative place for water funds, as usually proposed, suggests that local and state governments know what society needs and just lack fiscal resources. State capacity (and willingness) to deal with water problems is certainly a candidate for further enhancement through cost sharing. But a case can be made that even at state and national levels, much less local levels, incentives and interest representation are not identical with the public interest and that grants that provide for specific objectives can be a desirable tool in the hands of representatives of a federal point of view in water resources. Also for various reasons, some that will be explored shortly, the multi-state region is a channel for complementary federal aid that should be considered carefully.

The success of the Appalachia Regional Commission (ARC) suggests that in at least one case where governors succeeded in gaining access to complementary funding they provided a measure of political viability and vitality to the regional institution involved. An important part of the ARC program is cost sharing which is supplemental to that available from other federal sources, on a project by project basis. The ARC model cannot be pushed too far. For example, none of the similar so-called "V(a)" interstate commissions has shown the same program and budget strength. Nonetheless, it should suggest a closer look at basins as channels for water cost-sharing.

To sum up, the challenge is to provide principles that will lead to procedures for matching evaluation to the systems involved, reflecting and shoring-up the weakness of benefit-cost analysis at the project level. There probably are economies and program advantages in dealing with the extra local effects of projects in a unit separate from the several agencies; there may also be some advantages in achieving systematic evaluation. The monitoring and assessment function of some basin arrangements gives them a start on the process. "Independent" review groups need a political base somewhere and the governors are one place to turn -- the states should be pressed for more political accountability in the water field. Linking some cost sharing to the evaluation of extra local effects of the projects seems to make sense if localities are in fact to be well represented in project formulation. Stressing the implementability of non-traditional project means through cost-sharing reform may offer as much potential for improved performance as any other item discussed.

THE LOCAL VIEW

Land use, water and water quality management (including planning) can be perceived as integrated today in most meaningful terms, professionally (i.e., analytically) and politically (i.e., by interested publics) at the local level -- not at the state, federal-state river basin, nor federal levels.

Managed growth of localities is increasingly becoming a reality in the form of assistance to and constraint of private initiative in the local public interest. Public encouragement of local economic growth has long been a reality at the local level. Public constraint of local population and economic growth with the aim of realizing local social environmental values (i.e. in terms of industrial location, population density, open space, educational facilities, recreation opportunities, etc.) has been less pronounced, but is now being given increasingly strong public support (e.g., consider the court decisions with respect to Ramapo, New York, Petaluma, California, and Boulder, Colorado). Federal and state environmental support programs, including water quality, highway billboard controls, open space, wild and scenic river programs and others have encouraged this local public interest concern and helped to make it politically effective. Even the localities, strongly desiring local economic growth, do not want growth at any price today in terms of social and environmental values.

Local comprehensive land-use management is the primary instrument of managed local growth. The right of a locality to assist and constrain private initiative through appropriately formulated and adopted comprehensive land use plans is being increasingly recognized by the courts as Constitutionally valid (e.g., Petaluma case). Appropriate plans consist of a statement of public goals, objectives, policies (i.e., implementing criteria) and procedures (i.e., subdivision, zoning, permit controls). These are presented together with two dimensional maps generally indicating, if not always precisely defining, at any time, a visual representation of publicly desired goals and objectives. The opportunities and problems of water supply and quality management for domestic, industrial, recreational, and scenic use as well as safety from floods together with air quality, transportation and solid waste management, need to be considered in comprehensive land use management. But the mix and level of this management can best be determined in the context of local comprehensive land use planning and implementation.

However, land use planning can be effective only if the locality possesses, on a continuing basis, its appropriate "critical mass" of professional planners and managers. Planning at all levels on all subjects has progressed from the back of envelopes to increasingly professionalized forms. Within the United States there are few Federal or state grant programs which support development and continuance of local planning staff capability. All such aid is

now very short term. The funds for the multitudes of short-term "comprehensive" planning exercises (e.g. Sections 701 or 208, Law Enforcement Assistance Administration (LEAA), comprehensive health care) will be largely wasted if a local commitment to planning, or the professional capacity to perform it on a continuing basis, is not achieved. Federal and/or state categorical grants are needed to encourage and speed this type of necessary, local and professional performance.

Localities, of course, can be of many types: cities, townships, counties, councils of governments, special districts, and regional planning areas. Discussion of the institutional problems and opportunities presented by this multiplicity of institutions is being treated elsewhere. For purposes of this discussion, it needs to be said that the local institution performing comprehensive land use planning must be one that has general legal authority to manage private land use in the public interest. If it does not have this authority, then it must be in a position to influence strongly local management through Office of Management and Budget Circular "A-95" review and related procedures. Planning without a close relationship to public management decision-making is meaningless.

If land use, water and water quality management can be perceived as integrated most meaningfully today at the local level, what is the planning and management role at the state, federal-state and federal levels? Or, putting it another way, if the meaning of all decisions can be clearly perceived together at the local level, then which of those decisions should be state decisions or federal decisions? What should be the role of federal-state river basin commissions?

State decisions should be confined to specific matters of state interest. These matters will vary from state to state, but they could include final authority on location of general aviation airports, power plants and transmission lines, new cities, large industrial plants outside cities, state parks, greenbelt, or wildlife areas and state highways; or on water quality effluent permits, stream classification or ambient air standards, ground and surface water rights, or state water development facilities that benefit more than one locality.

Federal decisions should be specifically limited to matters of federal interest. Such decisions can be classed in at least two categories:

- a. Decisions to approve or deny state or local grant requests on the basis of some general criteria applicable across the board.
- b. Decisions where a federal discretionary judgment is being made that could impact significantly local land use plans. These latter decisions are very important with regard to intergovernmental relations and should be clearly defined so that the public is aware of the locus of responsibility.

Federal decisions reflecting federal interests could or do include such matters as location of major airports, major energy production and transmission facilities, water resource developments having widespread benefits (usually interstate), national water pollution control standards, national wild and scenic rivers, forests, parks, wildlife refuges, or lands to be held in agriculture by an appropriate incentive scheme.

Planning involving federal, states and localities together is for the purpose of settling conflicts involving the use of their respective authorities and for assuring appropriate complementarity of decisions by two or more levels were appropriate. Settling conflicts and assuring complementary decisions are usually made ad hoc from time to time. But often they could best be made after an extensive and intensive multi-level planning exercise has been undertaken following the lines of established local interest, state interest and federal interest. Federal-state river basin commission and federal-state economic development commissions could be used for this purpose more than they are today.

REINFORCEMENT OF LOCAL GOVERNMENT AT THE LOCAL REGIONAL LEVEL

The prospects of meeting societal needs for water and land resources quality and quantity can be better served if planning for these ends is more effectively integrated, particularly at the state and sub-state regional levels. One very direct way of achieving such integration would be to consolidate certain of the Federal grant assistance programs supporting quality, quantity and land use planning. The work group suggests that consolidation be explored.

A reasonable place to begin would be consolidation of certain grants specifically for water resource planning. Key programs here could include Title III of the Water Resources Planning Act (which assists the states for "comprehensive" water resources planning), Sec. 208, P.L. 92-500, for area-wide management plans and Sec. 303 (e) P.L. 92-500 for basin plans as part of a continuing planning process funded through Sec. 106 of the 1972 amendments.

There are problems in connection with each program in achieving the objective - a capability and continuing process for linking water resource quality and quantity needs, alternatives, impacts and programs at state and sub-state levels.

The Title III program is small -- very small. The current annual authorized level is only \$25 million nationwide. Both legislative history and administrative practices have tended to confine use of the funds to the state level (little pass-through to sub-state planning entities). The Sec. 208 program is conceived as of limited dimension.

Certain elements of the 303 (e) process are tied specifically to certain regulatory features and may not be easily (or wisely) incorporated into a broader process looking at resource management needs (in both quality and quantity), alternatives, water-land relationships, etc.

Nonetheless, a single grant mechanism to state and sub-state planning which encourages the integration of quality and quantity considerations with each other and with land (and other) considerations, would, by definition, help to breakdown the quality/quantity barrier in planning at these levels which is fostered by fractioning grant assistance.

A consolidated grant incorporating appropriate elements of these three programs could be administered by the Water Resources Council as the point in the Executive branch in which comprehensive planning perspectives are sought.

An alternative would be to add the Title III objective (and appropriate funding) to the purposes founded by Sec. 106 P.L. 92-500 with appropriate language and legislative history assuring participation by Water Resource Council agencies in how the program is administered.

In either event, this proposal implies making the Sec. 208 process (that is, of water quality strongly related to land use and development problems) a continuous process whether funded under the present Sec. 208 through funds and appropriate language added to Sec. 106.

If this step toward water quality quantity-land relationships proves productive, it might possibly bring other land and natural resource grant assistance programs into a consolidated grant mechanism, while leaving the grant mechanism for implementing actions in the present administering agencies. For instance, the program development (planning and legal and institutional analysis) Phase E of the Coastal Zone Management Act is a prospect. Others include the planning ("Strategic Outdoor Recreation Plan") of the Land and Water Conservation Fund grant assistance program for outdoor recreation. The physical planning aspect of Sec. 701 (Housing Acts) grant program, currently requiring a land use element, is another.

Integration by EPA of air, solid waste and water supply planning assistance programs (whether or not they are specifically identified as such) would accomplish important integration objectives among these important programs and improve prospects of evaluation of total environmental protection programs in relation to other land and natural resource concerns, objective and programs.

Some further thought should also be given to Sec. 209 of P.L. 92-500, requiring to complete "Level B" comprehensive basic plans nationwide by 1980 with priority to 202 - related basins.

The "Level B" antecedents in basin planning have historically served as vehicles for inter-agency federal involvement in planning which concentrated on extolling the desirability of federal funding of resource development projects.

Under the Council and the river basin commissions which have done most recent Level B Planning, state and sub-state planning agency involvement has increased markedly and the studies have considered and recommended management actions by all levels of government (not just federal) for nearly the gamut of water and related land objectives and uses.

In short, the Level B study is designed to be an integrating vehicle. Unfortunately, as noted earlier, the principal vehicle for federal financial support for comprehensive water and related resource planning (Title III of the Water Resources Planning Act) is small and largely limited to support of capacity-building at the state level.

Sec. 209, too, might be made a vehicle for water quality-quantity and related land considerations at state, basin and 208 scale levels. A way of channeling funds to assure effective participation at both state and sub-state levels would have to be worked out to fully realize their potential. The consolidated water resource planning grant programs suggested earlier might also be so designed and funded as to accomplish this purpose.

Ultimately, more aggressive involvement by state and sub-state planning entities in water quantity problems, as part of an integrated quality-quantity planning process, will lead to a sharp increase in local and state initiatives in formulating solutions to water resource management issues. The work group deems this result desirable as contrasted to the present dependence on federal water resource development agencies, with their mission orientations and as planners, as well as potential implementors. We note with approval that each agency has a program for closer local cooperation in planning but urge more coordination through the proposed consolidated grant approach.

An integration and strengthening of water quality quantity-land use planning at state and sub-state levels may well lead to demands on the part of states and local governments for management grants for water resource (as distinct from water quality) management to implement solutions preferred by those levels to the solutions which can be executed through federal agency projects.

Given current public preferences, it seems like such state and locally initiated water resource solutions would tend to be less capital intensive, less structural and more environmentally sensitive than solutions produced through federal water resource development agency planning process and its traditional independent mode of project planning.

The work group considers those characteristics to be generally desirable as offering opportunity for optimizing selection of water resource management alternatives not meaningfully possible so long as federal financial support is confined to solutions which can be carried out by the federal agencies, with their current emphasis on sharing only capital costs of alternative solutions.

PUBLIC PARTICIPATION

The intent of the several statutory provisions and agency policies requiring public participation is to improve access by interested groups to public policy decision-making within the planning process, thereby improving the responsiveness of that process to the community.

Self-interest and established institutional arrangements are such that the beneficiaries of governmental resource developmental programs have greater assurance of such access. The recent emphasis in federal/state and local legislation on public participation, thus, has the special purpose of improving the access of other interest groups, notably environmental-conservation interests (not in the sense of excluding other interests but, rather, to correct previous imbalances in that access). Accommodation of conflicting interests is important to the health of any program.

Variations in the constituency of the agencies concerned with water development and water quality are such that greater integration of these program areas should facilitate the resolution of conflict between competing interests.

All governmental agencies, in order to assure their continued existence, seek to develop a constituency supportive of that goal. Such constituencies are composed, in the main, of beneficiaries of each agency's activities. A major problem, therefore, is effecting conciliation/integration of the different publics or constituencies of the various agencies and other participants who hold "veto roles" for these programs.

Local governments, and planning activities that relate to local governments, have a special opportunity to utilize public participation to facilitate interest accommodation and public understanding due to the nature of public participation in public affairs. Most people do not participate at all. Half of the adult population doesn't vote; and for about one quarter voting is their only political act. Most of the remainder content themselves with a few fairly positive activities beyond voting such as a letter to a Congressman, contribution to a party or organization, or attendance at a public meeting. A fraction of one percent surmise the issues and alternatives, seek consent for a course of action, and do all the other things that lead to public

decisions. Most of this participation is at and through local governmental activities.

Thus, the recruitment of only a few more activists can add substantially to the effective public understanding of a problem area. Public participation activities should be directed to that end.

INTERREGIONAL PLANNING OF WATER SUPPLY*

This topic will be broadened somewhat to discuss a whole set of interrelationships and side effects. In a rather classic article in the American Journal of Agricultural Economics some years back a couple of our colleagues at Utah State University showed the efficiency gains of allowing free sale and purchase of water among four irrigation companies, operating in a small area in Utah.^{1/} This idea is the same one that pervades the presentation Dr. Keith has just made.

The long-term average expectations of water supply and the possibility of compensating shortages with surpluses is a strong motivation for planning on a multiregion basis. But still another motivation is found in the insurance against the short-term variations in which one region may relieve shortages of another.

The need for interregional planning really arose with the demise of the cowboy economy. When any person could no longer use up, despoil or waste resources without any harm to another, the need for interregional cooperation began. No man is an island. Nor is any city or region.

I wish to go beyond the scope of our studies within the boundaries of Utah to indicate the nature of some of the interregional studies we are engaged in. Many of these efforts sprang from our initial efforts funded by the Corps of Engineers which ended about two years ago. As we embarked on that effort, we thought we could foresee a succession of

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^{1/} B. Delworth Gardner and Herbert H. Fullerton, "Transfer Restrictions and Misallocation of Irrigation Water", American Journal of Agricultural Economics, Vol. L, No. 3, (August 1968), 556-571.

studies that would be immensely useful as academic exercises in developing methodologies as well as real contributions to decision making and planning.

We are now involved in several studies of the Colorado River Basin. This river system exemplifies a classic case of market failure or externalities. The upstream water user produces more than optimal quantities of pollutants (primarily salts) because he is not forced to bear the costs of his actions. Thus, the full social costs of upstream actions are not taken into account in the production decisions. Studies indicate that for each mg/l increase in salinity at Imperial Dam the increase in damages to downstream users amounts to about \$200,000 annually. These are in addition to the damages occurring in Mexico. President Nixon promised Mexico a desalting plant to take care of their problems. By all indications, this plant and its operation will cost us far in excess of the damages the Mexicans are incurring and far in excess of alternative means of reducing the damages. Here is a prime example of where interregional (international) analysis and negotiation might have saved us some money, but political realities forced us into an apparently inefficient solution. A number of capital intensive measures of reducing salinity at Imperial Dam would cost more than the values of damages averted. However, some of the less capital intensive measures might cost less than the benefits realized from salt reduction. The point is that a comprehensive analysis of upstream costs and downstream damages must be made before an efficient course of action can be developed.

One of the solutions proposed for reducing the salinity going into the river is to require total containment of industrial uses of water such as for energy uses in the Upper Basin. Thus, the loading of salt

back into the river is avoided. But, relatively high quality water in the Upper Basin is diverted and entirely consumed. Thus, less water is left in the river for dilution. Since about 2/3 of the salt in the river comes from natural sources, the loss of water for dilution may more than offset the gains from reduced loading. Again, the problem must be addressed in a total systems context, which is the goal of inter-regional planning. In the same vein, the requirement for "End of Discharge" in 1985 for agriculture as required by PL 92-500 is an "Impossible Dream". Only five percent of the irrigated acreage in the Colorado Basin is artificially drained. It is not physically possible to alter the laws of nature which cause plants to use pure water and to let the impurities pass on in natural drainage channels. A downstream complaint which results in such a regulation is not worth paper for printing. A less stringent proposal is to increase irrigation efficiency. This would reduce the water passing through the crop root zone and passing through the salty soil profile. Viewed simply, this seems to be a promising solution to the interregional problem. But, our studies with soil physicists and agricultural engineers indicate a salt buildup in the root zone if water is not continually passing through this root zone. Evaporation is continually pulling salt to the surface which cuts crop production and profits by a greater proportion than the increase in soil salinity. This happens within a period of a few years with water quality at 1/10 to 1/30 as much salt concentration as the Black and Veatch study shown us by Mr. Gaum earlier in this conference wherein it was alleged that very poor quality water could be used successfully for irrigation in the Red River Valley on the Texas-Oklahoma border. Perhaps this can be successful over a long time if drainage conditions are right. It would

appear that they used the USDA Riverside Salinity data and assumed plentiful water and perfect drainage conditions.

This same kind of application of an outside observation has led to miscalculations of agricultural damages downstream in the Colorado. For many years, the only comprehensive evaluation was in the form of a Ph.D. dissertation at the University of California, Davis which dealt with the Imperial Valley. Essentially, all evaluations were based on this piece of work for lack of any other data. It is a recognized fact that the soils in the Imperial Valley of California are very heavy with poor drainage characteristics. Thus, it is difficult to force enough water through the root zone to prevent a salt buildup. Yet federal agencies and others have invested many years of planning and evaluations costing millions of dollars based on the assumption that damages in other regions had the same relation to gross value of crops per acre as could be obtained in the Imperial Valley.

For a different kind of example, in the aggregate the people of the Upper Colorado Basin and of the Little Colorado Subbasin of the Lower Colorado (where the huge Navajo Reservation is located) are socially and economically disadvantaged as compared to other residents of the rest of the Lower Colorado Basin and the major export service areas in Southern California. A requirement such as is contained in the Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) that might place the burden of cost on the upstream contributors is a form of regressive taxation that might be avoided if the problem were looked at in an inter-regional setting.

Probably the most flagrant abuse of the investigation of each region being investigated in isolation is one that I encountered in Bangladesh

in South Asia a few years back. Huge dikes like the polders in Holland were being designed and constructed to contain and train three of the largest rivers in the world which converge on this flood plain which contains about 60 million people. Even the most elementary calculations of flows of these rivers indicated that these diking systems could not work together. The water would always have to be several feet higher than the banks to carry the water at annual flood stage. Yet separate contracts were let for each of many regions for design and supervision of construction as if no other construction was now or ever would occur. The bureaucratic bungling was simply dismissed with the comment that the projects could not be justified unless they were considered individually. For this mismanagement, I did not blame our friends from Asia. They had poor advice and dishonest contractors. The lesson was valuable to me, though. Hardly any investment or change in the system can be accomplished without something else happening somewhere else. Most things in a complex world are tied together.

Our studies in Utah indicate that substantial gains in social welfare can be attained by broadening to interregional and interdisciplinary considerations. To fail to do so is like wearing blinders so that we can see only straight ahead (or backwards). We had better internalize more considerations to gain credence for our work.

Regional Analysis in Planning for Water Supply Extension

by Stephen P. Coelen*

In the water supply industry it is typical to find numerous small and isolated water suppliers throughout a large region. Pennsylvania, for example, has over 900 water suppliers of three different types--public (municipally owned) firms, private firms and municipal authorities. Alabama has over 1300 suppliers and other states have similarly large numbers of suppliers. The suppliers within their own jurisdictions have the monopoly power of natural monopolists and therefore typically are regulated as in Pennsylvania, by the state Public Utility Commission. However, regulation prohibiting non (economic) profit making has the effect of proscribing the suppliers away from the efficient production conditions of minimum average cost as well as from socially optimal outputs which maximize the net benefits of water supply (see Averch-Johnson and Bailey). Regulations coupled with smallness of size (670 of the Pennsylvania water suppliers service such small areas that their gross annual revenue is less than \$100,000) prohibits the firms from obtaining the capital for necessary plant expansion. The use of technical services (for example of engineers and accountants) is inefficient because of the size of operations. The ability to service presently unserved but neighboring communities is stymied because of the small size of existing firms. Regionalizing water supply should affect all of the above conditions.

There are two distinct situations in which regionalization may take place. These are (1) regionalizing two or more existing systems with no

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service extension but continuing service from combined production facilities to pre-regionalization customers and (2) regionalizing one or more existing systems with areas previously without service. These two situations differ in description of the physical details of the regionalizing project, but more importantly, they differ in respect to the way that project benefits may be calculated and the way that those benefits are distributed over the regional population.

Regionalizing existing water suppliers provides an integrated physical, fiscal and managerial program for two already existing component systems. This capitalizes on scale economies of decreasing cost with large jurisdictions. It can represent simple amalgamation of the variable factors of production--technical expertise and the like--or it can represent a more complicated situation in which a regionalized system operates without regional interaction during normal times and interacts with its regionalized partner only in times when supply is short, then the water short partner borrowing from the water rich partner. This latter really is analogous to insurance policies in which the main rationale for regionalization is the sharing of risk.

Risk sharing is not a highly promising avenue through which regionalization will occur in the humid eastern United States because the hydrologic variations of available water supply, relative to average available supply, tends to be correlated among systems sharing the same source, say a river water basin. The ability to efficiently regionalize is impeded unless regional partners are drawn together from differing source supply areas or from areas where at least one system finds its average available supply in great excess of quantity demanded at a reasonable price structure. In the first case, however, prospects of regionalization are weakened, because

the risk sharing benefits are balanced by high regionalization costs due to the extended distance between potential partners of different hydrologic areas. In the second case, regionalization prospects are weakened because the water rich area has nothing to gain from regionalization unless it is the monopoly profits of selling their own water to neighboring draught areas at such high prices that neighboring suppliers will balk at regionalizing.

The major way in which risk sharing becomes important in regionalization is when new supplies must be generated to serve as backup for draught periods. Because of the bulkiness of investment (see Warford), the small suppliers, prevented from capital accumulation because of regulation may not be able to finance individual projects. Acting together as a regional system their size may be sufficient that they can obtain necessary capital funding through loans or bonds. In addition, even if the individual suppliers could obtain capital, it is likely that the regional risk-serving water supplies can be developed at lower average cost than individual supplies. The regional system should not have to develop any less backup supplies than the sum of the individual requirements because of invariant regional hydrology. Nevertheless, the regional system, to provide storage for large quantities, may find, even it is incapable of providing any more water for draught periods than the sum of the individual abilities, that it can reduce the costs of shortage over the regional system. This will occur whenever there is an uneven distribution of water uses among the individual systems so that if rationing does take place there is more flexibility to ration among low valued water uses regardless of which individual jurisdiction contains the uses.

Regionalizing existing suppliers with non-serviced areas so as to extend service usually involves only enlargement of the existing supplier.

This requires increased capital expenditure for expansion of treatment plant and reticulation system. It also involves corresponding increases in variable inputs.

The benefits of regionalization in the two situations are distinct. In regionalization of existing suppliers, benefits are primarily in cost reduction. These are of real value because the savings, either to the consumer or the municipality, can be spent on other valued consumption. In this case, there is only a minor amount of benefit to be calculated from changes in consumption of water service, itself, as prices change. They are insignificant because of the likelihood that the average demand for water supply will be inelastic over the range of the relevant price change. Contrary to the first case, benefits of service extension are primarily captured by the increasing value of water supply consumption. These benefits are augmented by the large consumers' surplus that accompanies the original infrastructure capital of the reticulation system itself. These benefits represent the willingness of individuals to pay for the capital development of a reticulation system over and beyond what is actually charged for it. These consumers' surplus benefits have been found to be transferable into the property market, and so service extension benefits are likely to contain elements which can be partially measured by increasing property values.

The perplexing factor in regional water supply is that while regionalization looks on paper as though it yields some net beneficiality, in practice it is rarely adopted. This acid, market test can be interpreted as an indication that the paper results are wrong, but that is not a necessary conclusion. It is equally plausible that the empirical induction should be that the paper work on the theoretical efficiency benefits is correct but that the

distributional equity effects have simply not been considered. This later hypothesis maintains that in cases where regionalization is warranted because benefits are greater than costs, projects often will not be adopted because the benefits are distributed to few individuals while the costs are spread among many.

Much of the early discussion in this paper heralds this conclusion. Consider three examples:

1. In regional system integration, with water rich and water poor partners, regionalization may fail because either the rich gains monopoly profits in selling water to the partners who balk at such high prices or the poor gain water at reasonable prices but the water rich partner gains nothing. A compromise in which both (water) rich and poor are made each a little better off is always possible if the project is, on net, beneficial, but the market forces of bargaining may be such that the compromise will never be autonomously struck.

2. In regional system integration, the plausibility of reducing the water shortage losses by rationing among regions to eliminate the least valued use depends upon variations in uses among regional members. At the worst, if there is no variation, then individual systems can ration as effectively as a regional system. At the best, if there is variation, the regional benefits come to the edification of high-value water use regions at the expense of low-value water use regions. The regional benefit can only be accomplished at distributional (equity) disruption. While it is true that the net benefits could be redistributed among the components of the region so as to make each better off, this may not occur through any accommodation of an uncontrolled market.

3. In regional service expansion, the consumers' surplus benefits transferred into the housing market are likely to have large distributional consequences. Depending upon land and water conditions within the region, such service extension can dramatically affect housing market supply through facilitating density changes, especially so as the decision to provide water supply affects later or concurrent decisions to provide sewerage service. The extent of windfall profits to development entrepreneurs and builders is enough that the whole planned pattern of regional land use may be distorted by the service extension (see, Washington Post). The division of benefits among individuals within the the region depends upon housing market conditions (see Coelen and Carroll). The net benefits may be sufficient to make the components of the region each better off with correct distribution, but no market mechanism guarantees such a result.

The distributional problem is one which has been neglected in research on regionalization. We have little evidence that when government intervenes in the market to establish regional systems that the government is not acting in a position of advocacy for some individual (or community) or another. We equally have little evidence to the contrary. All that we can establish is that there seems to be some "grass-roots" growing awareness that the issue must be evaluated. A report prepared for the State of New Jersey by the Department of Community Affairs and Division of State and Regional Planning opens:

In recent years, there has been a growing concern that large public works expenditures [including regional water and sewerage projects] are spawning rapid and unanticipated development . . .

and concludes as an afterword that:

[An] area worthy of review which this research effort brought to light is a study of the unearned increment of value bestowed upon private property as a result of public expenditures By identifying areas of windfall profits and calculating their value, the public could consider recouping their value, perhaps in the form of a tax. Such revenues, for example, could be used to acquire certain undeveloped lands that might otherwise convert quickly to development as a result of the public expenditure. Another use of these funds might be to compensate owners of property which lose value as a result of such action. While a recoupment system would not be a cure-all for our current growth problems; it could work to discourage land speculation and thus promote greater equity in land value.

While these statements are not sufficient to cover the full range of equity questions which have been raised here, they are indicative of the kind of governmental concern of which we need more. If we are going to achieve the efficiencies of regional plans, we will need to have data on equity of those plans so as to make the plans acceptable to the populations involved.

Bibliography

Averch, H. and L. Johnson, "Behavior of the Firm under Regulatory Constraint," The American Economic Review, Vol. 52, No. 5 (December, 1962) pp. 1053-1069.

Bailey, E., Theory of the Firm Under Regulatory Constraint, Heath, Lexington, 1972.

Coelen, S.P. and W.J. Carroll, "Measuring Change in the Housing Market: A Comment," unpublished manuscript submitted to NBER.

Department of Community Affairs and Division of State and Regional Planning, "Secondary Impact of Regional Sewerage Systems," June 1975.

Warford, J.J., "Water "Requirements": The Investment Decision in the Water Supply Industry," in R. Turvey (edit.) Public Enterprise, Penguin, 1968.

Washington Post, article, January 1, 1974.

EFFICIENCY IN INTER-BASIN WATER TRANSFERS*

Introduction

The analysis of inter-basin transfers of water was undertaken as part of the mathematical programming model of supply and demand for water in Utah. The demand portion of the model was described previously in our presentation on Assessing Agricultural Water Demand. In this paper, the supply model will be described and the application of the total model will be discussed. Some current modifications will be briefly outlined and, finally, conclusions which might be drawn from the study will be suggested.

Supply Model

The supply model consists of a mathematical program which utilizes various sources to provide water for specified activities. Each of these sources is associated with a production cost. In the case of presently developed sources, operation and maintenance costs are distributed over the amount of water provided from the source. These operation and maintenance costs included labor and material required for normal upkeep and operation of water delivery systems, such as canals and other delivery structures, to the user.

For the sources which were not previously developed, costs associated with construction were added to projected operation and maintenance costs to arrive at a cost for "new" water sources. These costs were also

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distributed over the available units of water from the source after development. The development of several inter-basin transfer systems which have been proposed or are currently authorized was included in the model. These inter-basin transfers consisted of the Bureau of Reclamation's Central Utah Project, and several locally-planned transfers. These sources were, of course, higher cost sources. The entire array of water sources and their associated costs made up the supply function for water. The shadow price was obtained by increasing the requirements which the model would have to meet at a minimum cost. The curve was, of course, upward sloping as in Figure 1.

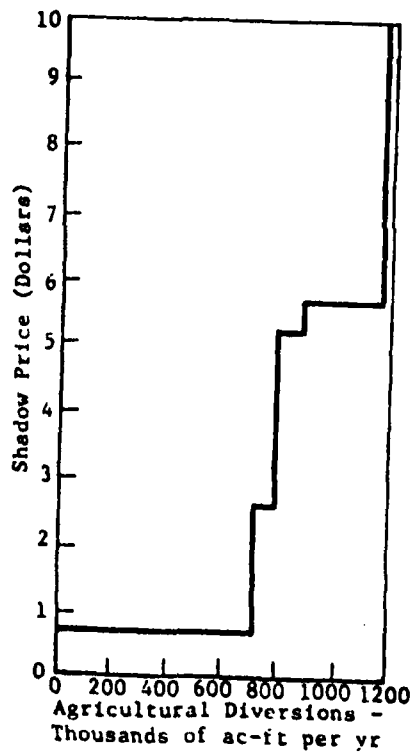


Figure 1. Supply curve for HSU 4.

There may be some objection to using an "average" cost for the supply curve in this model, rather than a true marginal cost. Since this average cost is generally what is charged for use, it appears that the allocation of resources will be based on those charges. To approximate the "real world" situation, these average costs were used. Further, given that construction costs are yet to be made, and therefore are variables, there is some justification for distributing them over the addition to water supplies.

The Application

The demand and supply models were then combined in the allocation model for Utah, as diagrammed in Figure 2. The model maximized net returns or profit, from agricultural use of water given municipal and industrial (M & I), and wetland requirements. By using projected water requirements for municipal and industrial users, the changing water allocation for the state could be examined. The timing of the development of alternative sources was also indicated. In particular, the development of the Bonneville Unit of the Central Utah Project was examined. It was clear that the timing of the development was dependent on the growth of M and I requirements, since the value of water in agriculture, a maximum of about \$25 per acre foot, was not sufficiently high to warrant importation costs (about \$80 per acre foot). Furthermore, various policies which restricted the use of some sources of water caused the timing of the transfer to be hastened. Two specific restrictions were examined: 1) inflows to Great Salt Lake, and 2) groundwater pumping.

As inflows to the Great Salt Lake are reduced, the level of the Lake falls. Since the Lake is very shallow along the shore lines, a significant reduction in inflows leads to the exposure of considerable amounts of Lake bed. Local decision makers generally oppose activity which reduces Lake levels for esthetic and recreational or tourism reasons. Water which could otherwise be utilized in agriculture or M and I uses is required to maintain Lake levels.

In Utah, groundwater pumping is restricted so that no well can be developed which will reduce the present artesian head of the groundwater reservoir. Groundwater in the Jordan Basin is plentiful. About 56,000 additional acre feet of groundwater could be pumped at safe yield, although artesian head would be reduced. Presently, much of the annual recharge which maintains the artesian head eventually flows into the Great Salt Lake.

The limitations on groundwater pumping for varying levels of surface water inflows were examined to determine the resulting timing of the development of the Bonneville Unit of the Central Utah Project. In Figures 3 and 4, these effects can be seen. Clearly, if pumping is allowed, development of the high cost imported water can be postponed until near the year 2000 while still maintaining the present Lake levels. For reduced Lake levels, even further postponement may occur. These institutional restrictions cause M and I users to pay a higher price for water than would have been the case if no restrictions were imposed.

The programming model results were used to calculate the additional cost water users bear as a result of the institutional restrictions. Supply curves were generated for the case along the Wasatch Front in which inflows to the Great Salt Lake were greater than or equal to

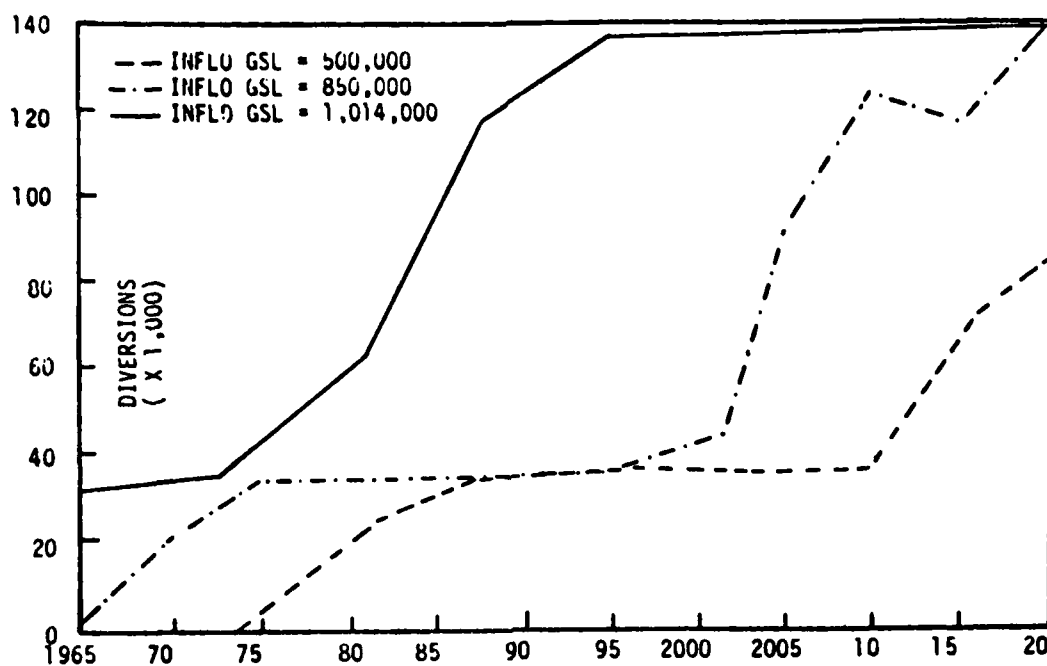


Figure 3. Bonneville Unit diversions with alternative INFLO GSL (no pumping).

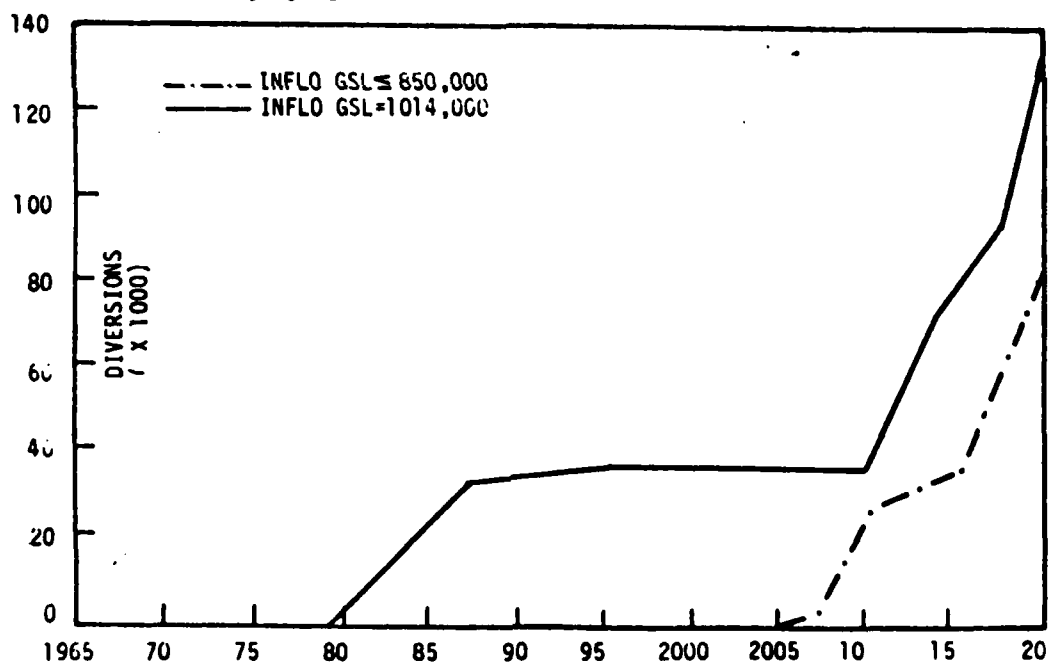


Figure 4. Bonneville Unit cup diversions with alternative INFLO GSL (with pumping).

850,000 acre feet annually, so that some water level reduction was allowed (as in Figure 5). For levels of requirements from 1965 to 2020, the allocation was examined to determine the addition to cost which users would have to pay, as in Figure 5. The difference between the supply curve S^4 and $S^{4'}$ is the loss to users which results from the higher supply curve over the time horizon and is presented in Table 1. These values are quite significant. The use of the model to generate these data about institutional restrictions appears to be straightforward and informative. Examination of institutional constraints on allocations and the costs which result should facilitate better decision making.

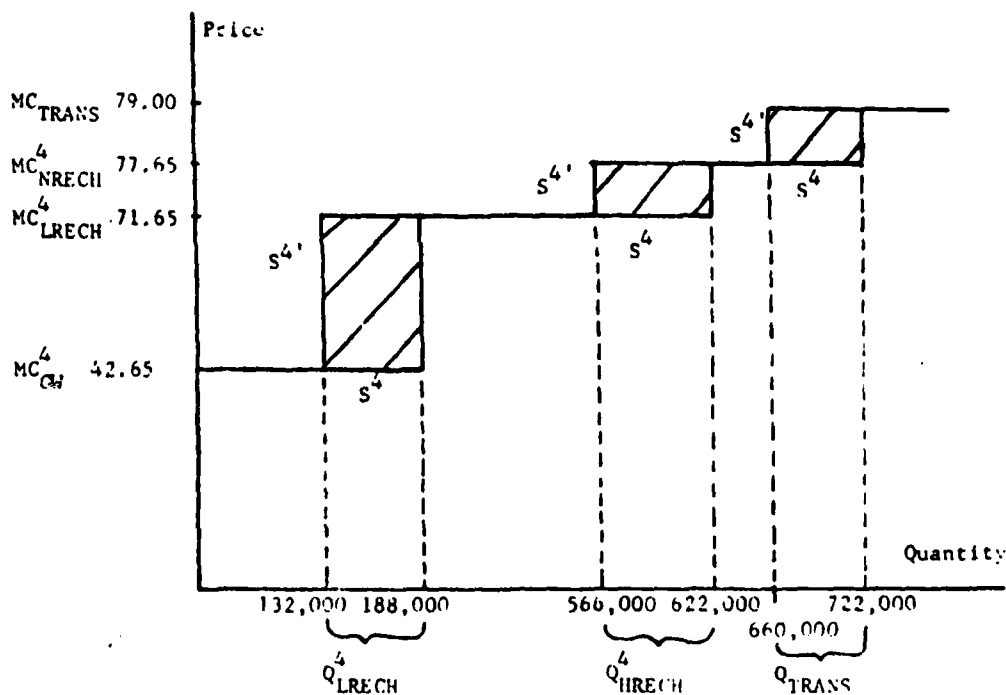


Figure 5. Supply curve in HSU 4.

The following symbols used in Figure 5 are defined as:

- MC_{TRANS} = Marginal cost of transferred water
 MC^4_{LRECH} = Marginal cost of low-cost recharge in HSU 4
 MC^4_{HRECH} = Marginal cost of high-cost recharge in HSU 4
 MC^4_{GW} = Marginal cost of new groundwater in HSU 4
 Q^4_{LRECH} = Quantity of low-cost recharged water to replace new groundwater
 Q^4_{HRECH} = Quantity of high-cost recharge to replace low-cost recharge
 Q_{TRANS} = Quantity of water transferred to replace high-cost recharge

Table 1. Present value of producers' surplus losses.

Interest Rate	Period Beginning	Present Value at Period Beginning	Present Value Discounted to 1972
5%	1980	9,521,000	6,446,000
	1990	10,773,000	4,482,000
	2000	12,118,000	3,090,000
	2010	12,702,000	1,994,000
			TOTAL 16,012,000
7%	1980	8,652,000	5,035,000
	1990	9,790,000	2,898,000
	2000	11,012,000	1,652,000
	2010	11,543,000	877,000
			TOTAL 10,462,000
12%	1980	6,961,000	2,812,000
	1990	7,876,000	1,024,000
	2000	8,859,000	372,000
	2010	9,286,000	121,000
			TOTAL 4,329,000

Current Modifications

With the advent of the energy crisis, water allocation problems in energy-rich but "water short" states such as Utah become important. This programming model is currently being modified to include the development of various energy production facilities in a manner similar to the agricultural demand portion of the model. In addition, studies of municipal and industrial demand functions rather than requirements are being utilized to include price responses of M and I users in the model. Allocations of water and the concomitant changes in economic activity in the entire state can be examined. At present, many of the Western States are delaying critical decisions about energy development, or making those decisions without an informative base. The modified model should provide substantial information on which to base policy.

Conclusions

Several general conclusions can be drawn from this study. First, these models can be used to generate information which is critical for policy making. Institutional limitations or constraints can be modeled in such a way as to reveal their direct and indirect impacts and/or costs. Second, these models can be modified to meet changing conditions to provide additional information to decision makers. Finally, the exercise of model building using a very structured approach allows interdisciplinary researchers and decision makers to develop better communications and more valuable information. It is, however, necessary to include the decision makers in the model building process to get their expertise into the model's structure and to assure their interest in the model's output.

INTEGRATING GROUND AND SURFACE WATER SUPPLY - EXPERIENCE
IN THE HUMID REGIONS OF THE U.S.

Gert Aron¹ and Walter Stottman²

Introduction

In contrast to the arid and semiarid West, where periodically recurring water shortages force water users to engage in regional planning efforts of efficient and coordinated surface and ground water use, the humid East lives in an atmosphere of apparent and possibly deceptive abundance of water. As a consequence, the Eastern states seem to get caught off-guard by an occasional drought as evidenced by experiences from the 1964 to 1966 period.

In general, groundwater is used to a much smaller degree in Eastern states than would be economically advisable. In many instances a city council will rather float a \$5 million bond issue to build a remote surface water reservoir and connecting pipeline than investing \$20,000 in a ground water exploration study because even a small chance of not finding good quality ground water might be politically disastrous to the officials who authorized this "waste of public funds."

A study was conducted at The Pennsylvania State University to investigate and quantify the role that ground water should play in planning for present and future allocation of surface water storage. Within this framework several questions were posed and answers sought, as follows:

What is the firm yield of a water supply system?

Is it the yield the system can provide under the worst possible drought conditions and if yes, then how is this drought generated? Historic stream flow

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records could be used but these records vary between a few years for some stream gages to almost 100 years for others, so that the lowest flow period of record would lack uniform base, namely the return period. A synthetic flow sequence can be generated, extending over hundreds or thousands of years but even such synthetic records depend on the size of the sample from which they are computed. The five to ten-year low flow could be used as another measure of design drought, but the critical duration of such drought periods must also be specified, and could vary between 7 days for a small community with only a holding tank for a few days supply to several months for a system with extensive reservoirs.

Could an occasional water shortage of a specified severity be tolerated and incorporated in the water needs planning process? If such an index of allowed water shortage is to be established, it should represent the monetary damages the shortage would impose on the demand system.

If both surface and ground water are available, what are the parameters which make the two sources economically competitive? Would the development of one or the other source be more economical than that of both sources?

If both ground and surface water supplies are used by a consumption system and neither of the sources are available in great abundance, should they be tapped as two separate sources operating independently or should their use be coordinated such that one source would essentially be used as a backup for the other?

Should the unreliability of population growth have an effect on the choice of the water source to be developed? If population growth patterns are deemed highly unpredictable, the more flexible scheme should be preferred over the more rigid and capital intensive scheme. Specifically, such a situation of uncertainty would tend to favor the development of ground water well-fields over reservoir construction.

The Firm Yield of Surface Water Sources

The firm yield of a natural stream is a highly elusive value. Whether historical or synthetic records are used, the firm yield will always be a function of the sample of stream flows on which the estimates were based. Especially where state or regional regulations mandate a minimum maintained stream flow, the guaranteed water quantity available for consumption may easily go to zero unless a reservoir is built to tie the demand system over a drought period. Even in the humid Northwestern United States, in which average annual stream flows usually amount to 1.2 to 1.6 cfs per sq. mi., low 7-day flows of less than 0.05 cfs per sq. mi., or 3 percent of average flow, have been recorded. Fig. 1 presents a dimensionless graph of firm yields Y as a function of reservoir storage capacity (both divided by the average annual streamflow volume Q). The graph was constructed from records from streams in the Susquehanna River basin, ranging in drainage basin size between 50 and 1000 square miles. The trend of the plotted points confirms that with zero reservoir storage Y/Q may well approach zero. Exceptions to this rule are limestone streams or very small streams originating in steep valleys of highly fractured rock.

Quasi-Firm Yield Subject to Occasional Rare Shortages.

Many communities have experienced now and then that an occasional water shortage is not the end of the world. It should therefore not be necessary to insist that the water requirements of a region be met an absolute 100 percent of the time.

A shortage index was formulated by the equation

$$MSI = \left(\frac{B \cdot SH}{D} \right)^A \quad (1)$$

in which MSI is the monthly water shortage index

SH is the water shortage in a given month

D is water demand in the same month

A and B are constants.

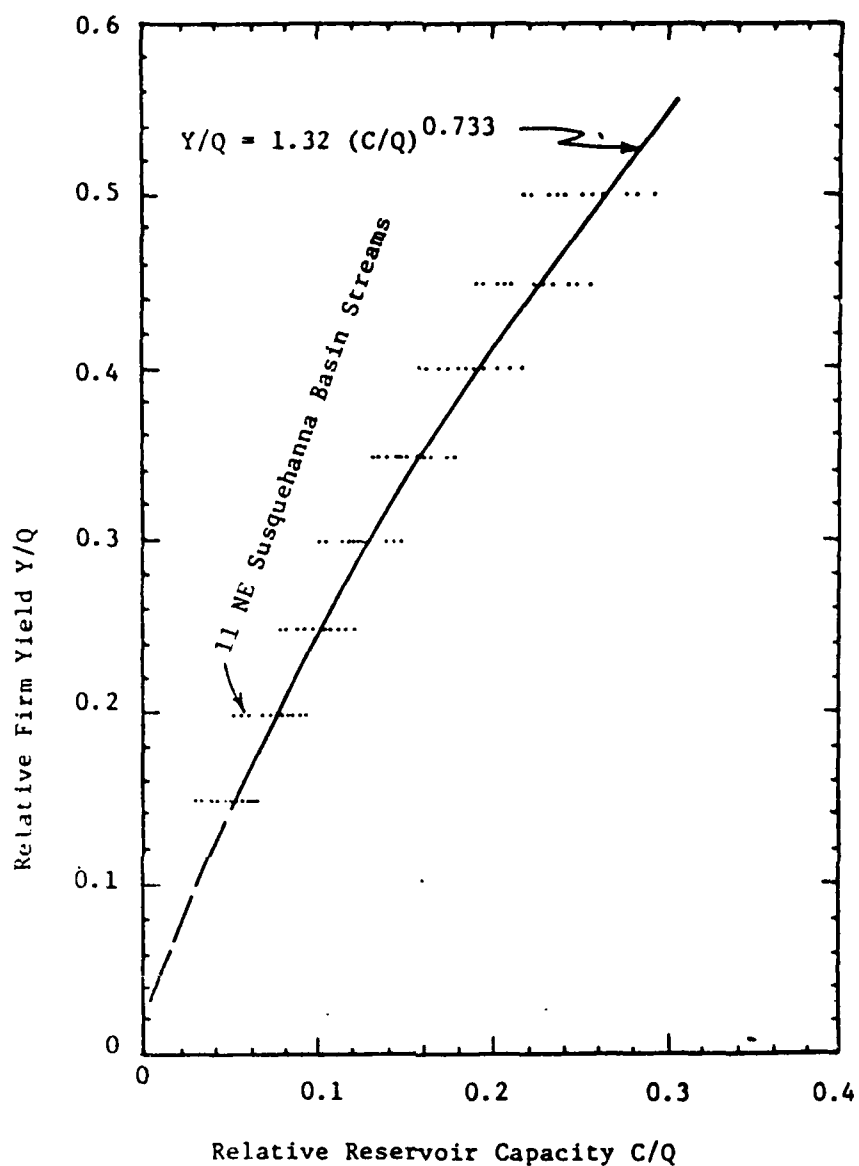


Figure 1 - Relationship of Firm yield to Reservoir Storage Capacity

A relative shortage SH/D of 0.5 was selected as the absolute worst shortage to be considered. Assigning a value of $B = 2$, the index was thus limited to the range $0 \leq MSI \leq 1$ regardless of the exponent A . A value of $A = 1.6$ was chosen, because it resulted in an index roughly proportional to monetary losses reported from estimates made in Lehigh, PA (Hufschmidt 1966). The average annual shortage index is the sum of all monthly shortage indices over the period of streamflow records, divided by the number of years in this period.

Fig. 2 illustrates the effect of maximum allowable shortage indices on the quasi-firm or dependable yield. A set of curves like this could allow planners to balance the savings accomplished by reduction of the reservoir size against the monetary losses caused by the occasional shortages.

Ground Water Use as a Backup Source

Ground water of good quality is often available near the demand center. The aquifer acts as a hidden reservoir, of limited and perhaps somewhat uncertain capacity. Depending on the aquifer volume it can be used highly efficiently to a smaller or larger scale as a backup water source.

Two modes of operation of this backup source were investigated: Under mode 1 ground water was to be called upon whenever the surface supply source suffered shortages. This scheme, while able to relieve the shortages up to a certain extent, tends to require a large installed pump capacity operating at a very low load factor. The second mode, called a system of preventive pumping, could be termed a panic button operation in that the water supply system manager would start drawing on ground water supplies well in advance of expected surface supply shortages. The preventive pumping rule would require the pumping of ground water whenever the surface water reservoir fell below a target carry-over storage expressed by the equation

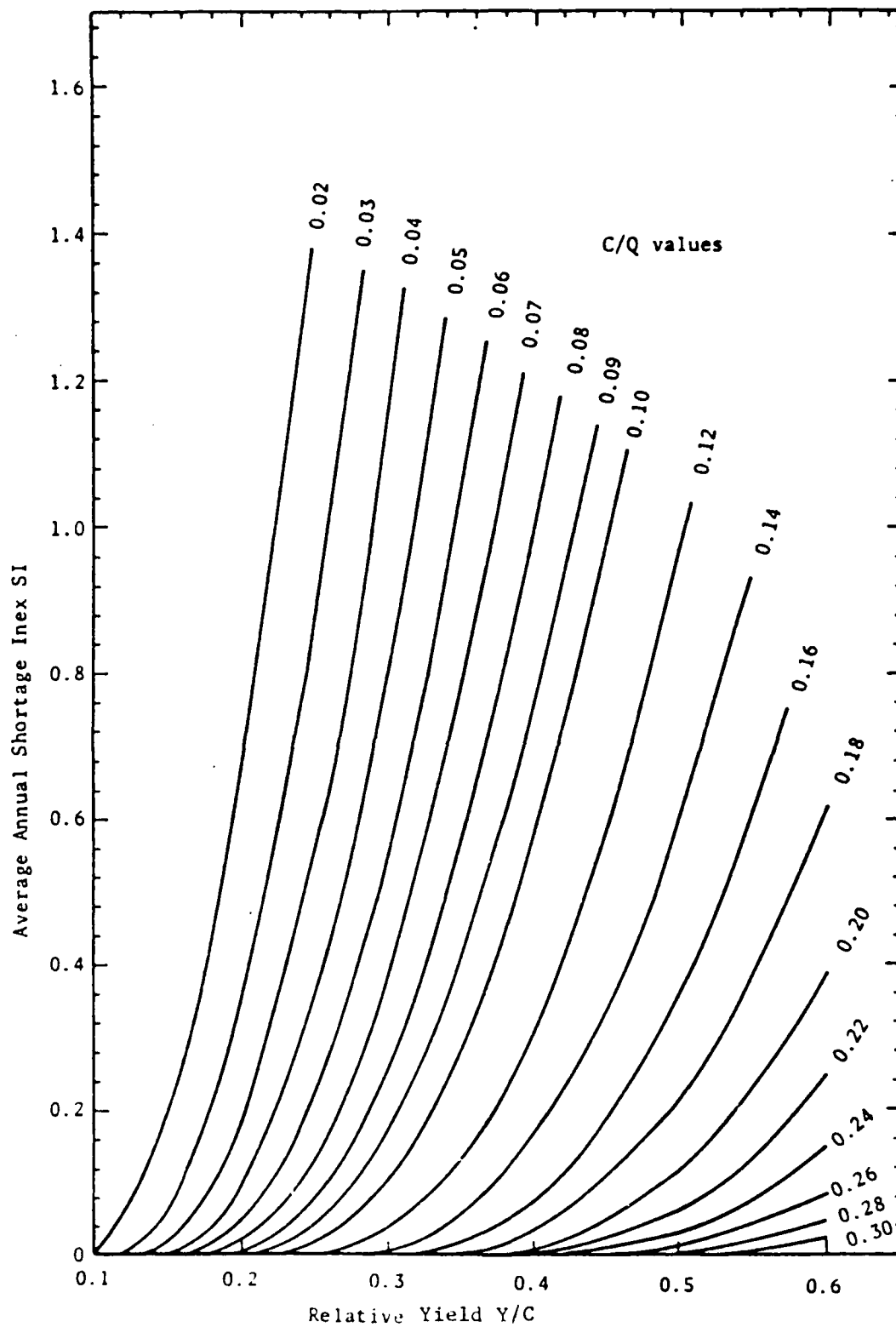


Figure 2 - Shortage Index as a Function of R/Q and C/Q

$$CS_1 = \sum_{n=1}^8 (D_n - EXQ_n) - (8 - 1) PMPC \quad (2)$$

in which CS_1 is the target carry-over storage at the beginning of month 1, D_n is the target draft during month n, including mandated low flow releases, EXQ_n is the expected reservoir inflow during month n, and PMPC is the monthly wellfield pump capacity.

A term degree of preventive pumping was devised, equal to the ratio between long term average streamflow and EXQ for any month. This ratio would be a degree of conservatism applied by the manager. A high degree of preventive pumping would require a large amount of surface water storage to be available at any time early in the season, as evidenced by the curves in Fig. 3, constructed for Newton Creek near Elmira, NY, with a drainage area of 28 sq. mi. and an average annual streamflow of 30.6 cfs or roughly 22000 acft per year.

With increasing degree of preventive pumping, the firm yield of a supply system increases, however, the volume of ground water pumped by the conservative operation schedule may exceed the aquifer capacity. Figures 4 and 5 illustrate the effects of the degree of preventive pumping and wellfield pump capacities on the annual combined yield and pumped ground water volume for Newton Creek at Elmira, NY, using a surface reservoir of 5000 ac-ft. volume.

A dimensionless plot of relative yields Y/Q as a function of relative reservoir size C/Q and wellfield pump capacity W/Q is presented in Fig. 6 in which W is the wellfield pump capacity in ac-ft per year and the other variables are those defined earlier. These curves demonstrate the decrease in reservoir size which could be achieved by using a preventive pumping degree of 5, providing the required ground water volume is available.

Finally, a set of isoquant lines were drawn in Fig. 7 providing the combinations of reservoir and well field pump capacities which could supply

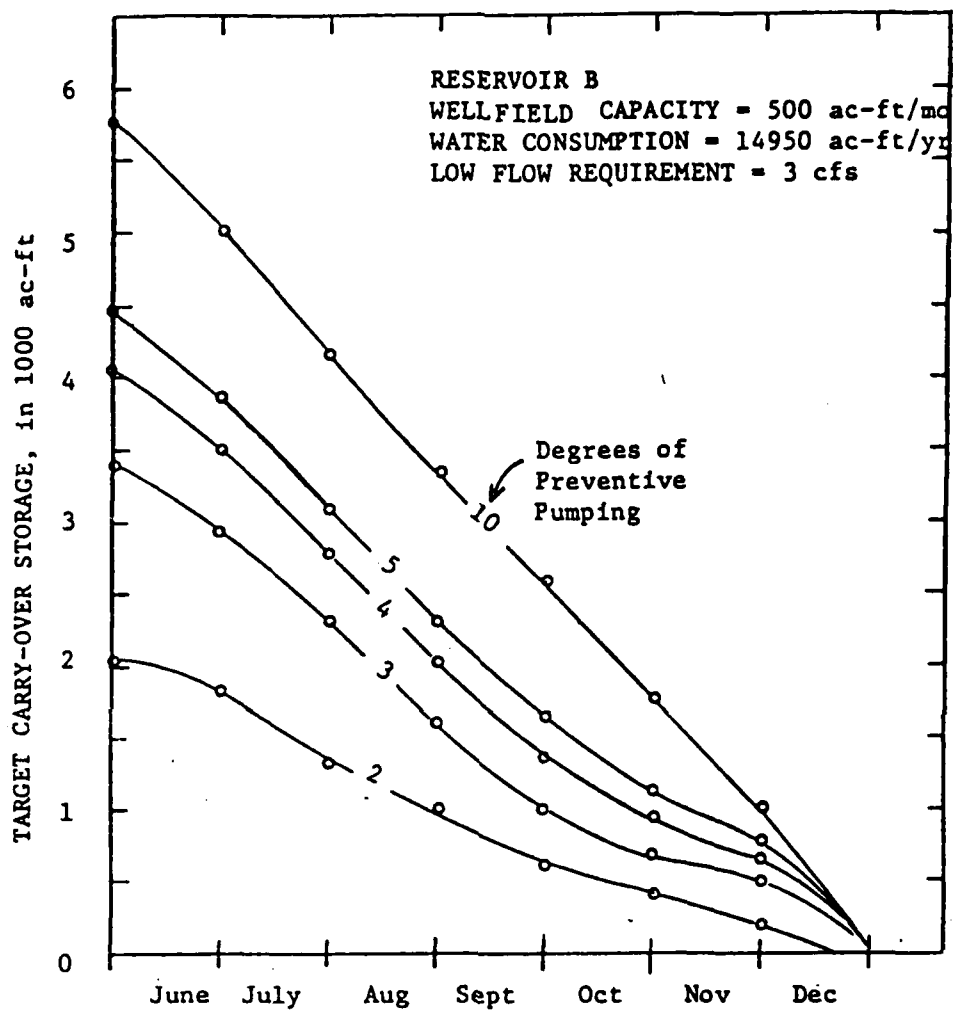


Fig. 3 - Target Carry-Over Storage Schedule as a Function of Degree of Preventive Pumping

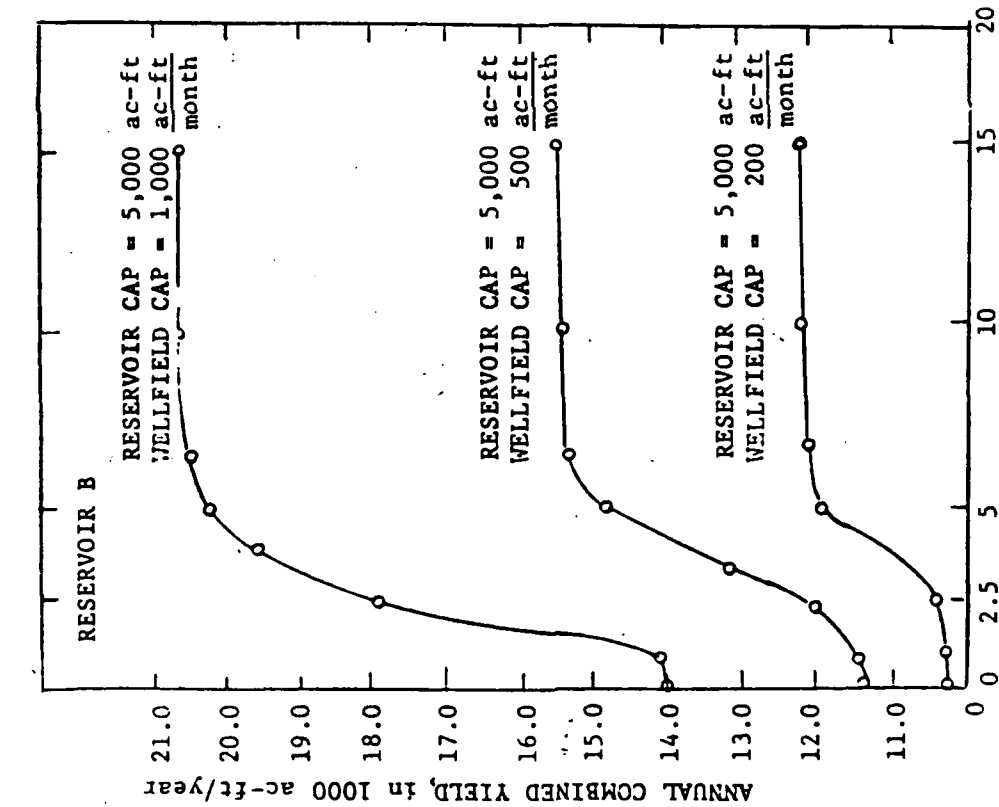


Fig. 4 - Relationship Between Annual Combined Yield and Degree of Preventive Pumping

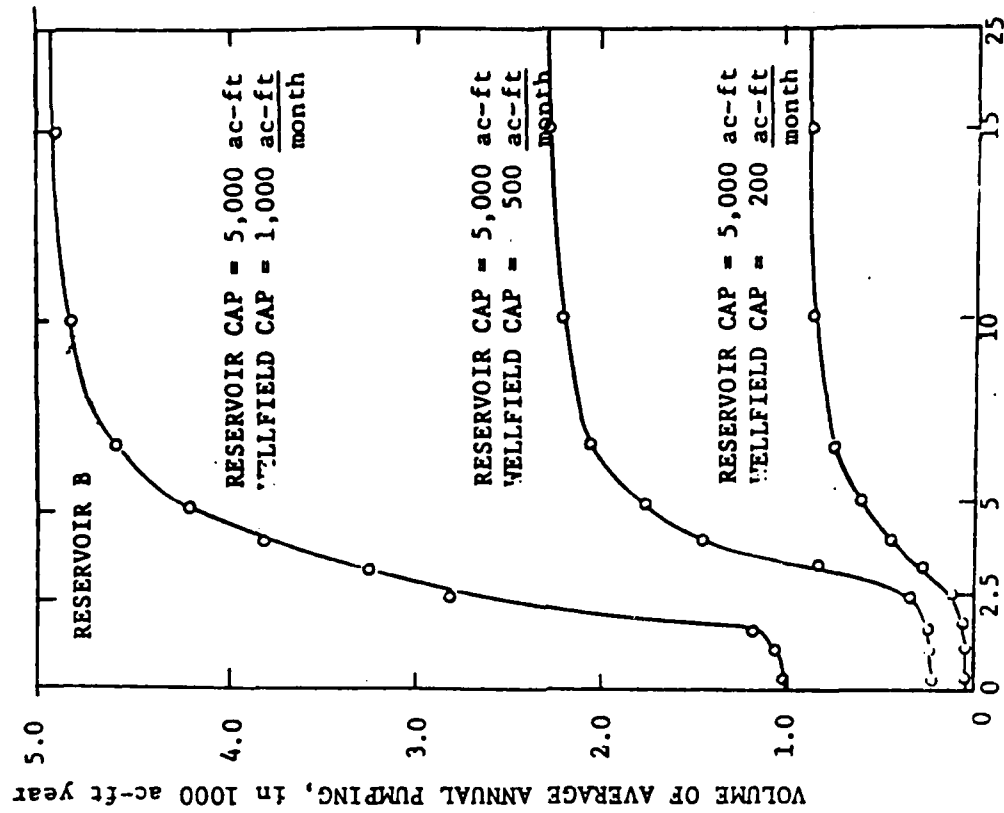


Fig. 5 - Relationship Between Volume of Average Pumping and Degree of Preventive Pumping

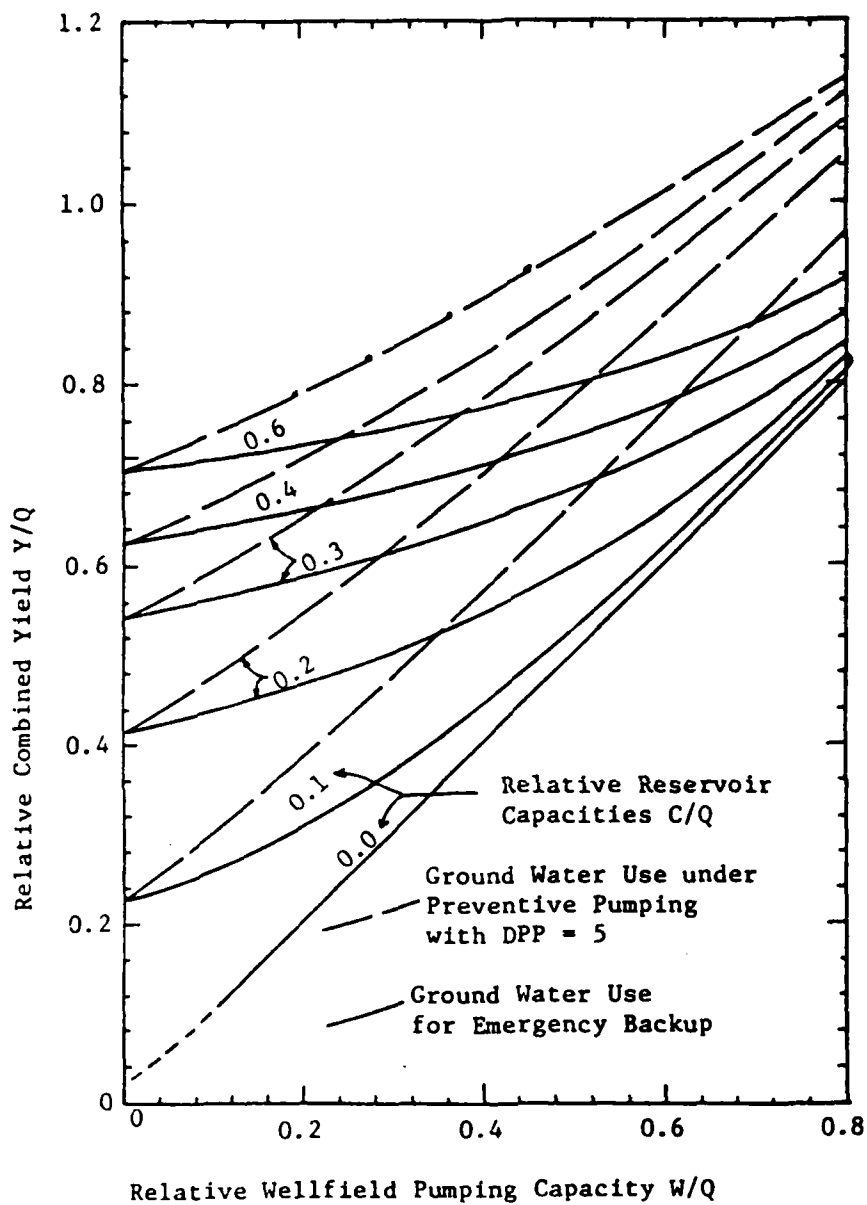


Fig. 6 - Effects of Relative Reservoir and Wellfield Capacities on Relative Combined Yield.

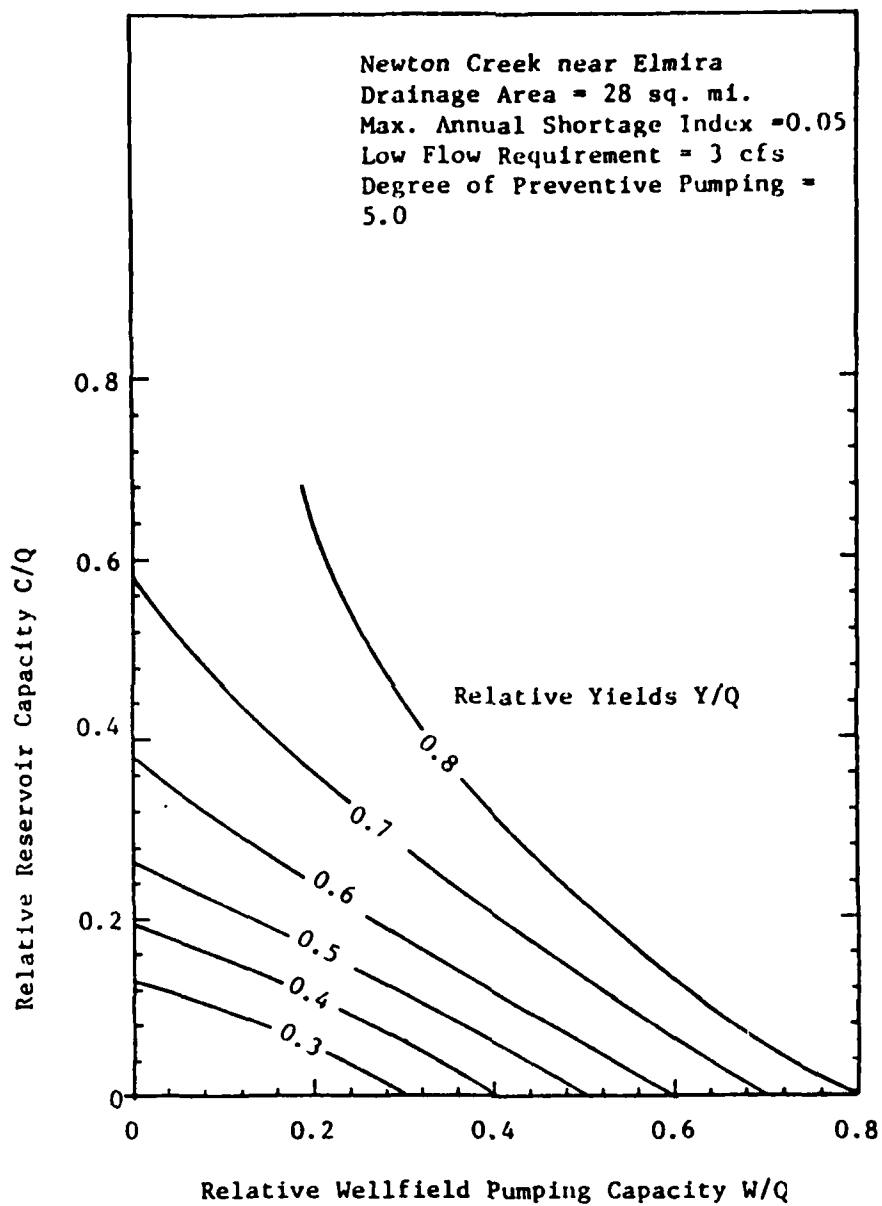


Fig. 7 - Isoquant Lines over a Range of Combinations
of Relative Reservoir and Wellfield Capacities

a desired relative Yield Y/C . Cost comparisons between the supply alternatives shown in Fig. 7 should be made to decide on the combination of ground and surface water scales and the degree of preventive pumping adopted. In a case of a toss-up where costs between the alternatives along any isoquant line do not vary considerably, it would be advisable to choose the larger surface reservoir, especially when population predictions are subject to uncertainty. The unused ground water reserves could then easily be tapped if the future demand for water should exceed the forecasted demands.

Conclusions

In the studies conducted at The Pennsylvania State University, the firm yield concept was studied on a sample of 10 watersheds in the Susquehanna River basin, varying in size between 50 and 1000 square miles. The studies showed that considerable savings in reservoir size could be achieved if certain occasional water shortages could be allowed.

A coordinated scheme of ground and surface water use was investigated. The results from a study on historic and simulated flows on Newton Creek near Elmira, NY, are presented in the form of dimensionless curves for planning the relative development scale of ground and surface water sources. These curves should not be used as universal planning tools but rather as a concept; it is recommended that similar studies should be performed on a large number of streams to find whether universally acceptable curves can be constructed.

References

1. Aron, G., Rachford, T.M., Borrelli, J., and Stottmann, W., A Method for Integrating Surface and Ground Water Use in Humid Regions, Institute for Research on Land and Water Resources Publ. No. 76, The Pennsylvania State University, February 1974.
2. Aron, G. and Coelen, S. P., Economic and Technical Considerations of Regional Water Supply, U.S. Army Engineers, IWR Contract Report No. 77, Fort Belvoir, VA, July 1977.
3. Hufschmidt, M. M. and Fiering, M. B., Simulation Techniques for Design of Water Resources Systems, Harvard University Press, Cambridge, MA 1966.

WATER CONTROL MANAGEMENT

FOR

WATER SUPPLY

BY

Vernon K. Hagen*

Many water resource planners may feel that water control management of existing reservoirs is a discipline outside their normal realm of study. However, if one is to plan for multipurpose reservoir development, there must be knowledge of the functional behavior of reservoirs and their management. Problems associated with water control management must be anticipated and plans adjusted to minimize or eliminate adverse impacts on the efficient regulation of reservoir projects. Some of the most serious problems connected with reservoir regulation stem from short sighted or inadequate planning and design.

This paper deals with the management of water supply from multipurpose reservoirs, primarily for municipal and industrial use. Single purpose reservoirs for water supply are seldom, if ever, built by the Corps of Engineers. With President Carter's concern about building too many dams in the U. S., future Federal reservoirs may be very difficult to build. Several factors will tend to discourage future dam building, including adverse environmental effects and safety problems. Therefore, it behoves water control managers to obtain maximum efficiency from existing reservoir projects. Planners become intimately involved in this objective by re-evaluation of basin water resource needs. With new priorities for reservoir storage, reallocation of storage within present reservoirs may become a real possibility. Present beneficiaries, however, become very indignant and hostile whenever modifications to their storage are mentioned.

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The Water Supply Act of 1958, permits the conversion of Federal reservoir storage to water supply if this action would not seriously affect the purposes for which the project was authorized. More significant changes or major structural modifications to the project require Congressional authorization. A serious problem evolves over what is a significant change in storage. The Chief of Engineers has authority to provide up to 15 percent of the total reservoir storage (excluding surcharge storage) for the purpose of water supply. This is of course the upper limit and any change must be well justified before it is implemented.

One common method of obtaining water supply storage in an existing reservoir is to change the flood control regulation plan. When the proper conditions prevail, revised regulation plans may permit essentially the same amount of flood control with less storage. Surplus storage may then be available for water supply. The most simplistic change in flood control regulation would be an increased reservoir release rate during flood events. This could be possible by downstream channel improvements, levee construction or other factors. Another effective means of obtaining water supply storage may be the use of seasonal storage. This is accomplished by filling a prescribed amount of storage at the end of the flood season for use during low flow periods. The storage is emptied by the beginning of the flood season. Seasonal storage is generally more effective for irrigation and recreation than M&I because their requirements are better suited to seasonal storage. Also, needs for storage may change after project construction, thus, making excess storage available. New projects may reduce the storage requirements of older projects for flood control or navigation. Changing conditions can also impact on storage requirements. For example: Good flood plain management practices downstream from a reservoir could reduce the need for flood control storage.

An item of particular concern in the planning of future water supply storage amounts is the yield that may be available because of the storage. In order to establish yield with a reasonable degree of accuracy, methods

of water management accounting should be understood. However, it must be clear that all yield computations are estimates. The Corps cannot guarantee specific yields of water supply to those that purchase storage in reservoir projects. Although several methods have been used to obtain estimates of reservoir yields, a period of record routing generally provides the most reliable results. This is particularly true, when the routing realistically portrays water management accounting that would take place during real time reservoir regulation. Routing periods may be longer during normal or excess flow with shorter routing periods used only during critical low flow situations.

Some of the important factors that should be included in water management accounting are reservoir inflow and its distribution (credits) among purposes (accounts), water use (debits) by purposes, evaporation (debits) equitably assigned to purposes, minimum release rate (in-stream flow requirement) and any constraints on water withdrawal from the reservoir.

During periods of excess runoff, distribution of reservoir inflow is generally not a water supply problem, as all conservation storage is usually filled. However, as the rate of inflow decreases, competition among conservation purposes can be a serious problem. Water rights are controlled by state laws and when not specifically identified by appropriated amounts or priority use, inflow should be distributed in accordance with amounts of allocated conservation storage. Thus, available inflow would be distributed 40 percent to water quality and 60 percent to water supply if their respective amounts of conservation storage were 40 and 60 percent. Any downstream appropriated water rights must be passed through the reservoir when not associated with reservoir storage.

As water is withdrawn from conservation storage for water supply, the water supply storage account is appropriately reduced. There are situations when conservation releases can serve more than one purpose. If water supply intakes are located on the stream below the reservoir, water supply

releases may also be used to produce power. When a reservoir release serves more than one storage allocated purpose, the storage loss should be shared by the purposes receiving benefits. Evaporation losses in large reservoirs can cause a significant reduction in available water for conservation purposes, especially during hot, dry weather. These losses should be shared by conservation purposes in accordance with their respective amounts of storage.

When reservoirs are constructed on streams that experience flow most of the time, it is usually impracticable to have a zero release rate, even during periods when inflow is nonexistent. A minimum release rate is generally specified by state water officials. Since storage is usually not allocated to assure this minimum release rate, the storage must be provided by the allocated purposes. Again, as with evaporation, the storage losses should be shared in accordance with amounts of storage.

The process for selecting minimum release rates has not been scientific in the past and has been a subject of considerable debate. Recent experience at American Falls Dam on the Snake River depicts the controversy that usually prevails when setting minimum release rates. When the gates at American Falls Dam were closed to begin filling the pool, the Bureau of Reclamation allowed 500 c.f.s. to pass for instream uses. Local irrigators objected on the grounds that inflow would not be enough to fill the pool in time for the irrigation season. Zero release would have caused adverse impacts on downstream trout. Thus, fish and wildlife interests insisted on an adequate instream flow. An agreement was finally reached by all interested parties that a release of 200 c.f.s. would be allowed. However, there was still concern that the flow would not be enough to prevent damage.

The need to establish a national basis for selecting instream flow requirements has resulted in a special organization to study this subject. The U. S. Fish and Wildlife Service has established a Cooperative Instream

Flow Service Group in Fort Collins, Colorado. Their objective is the identification, description, and evaluation of strategies for reserving flows for fish and wildlife. Several agencies, both state and Federal, have been cooperating in this endeavor. Although the Corps has not been an active participant yet, efforts are being made to include representation by the Corps. The Service Group publishes information on their activities in a paper titled, "Instream Flow Briefs".

Water supply contracts for some reservoirs may contain a constraint on the allowable rate of withdrawal. The reason for such constraint is to avoid adverse impacts on recreation benefits by rapid draw down of pool levels. The costs for water supply storage can be significantly reduced by including recreation as a project purpose and allocating costs to recreation. Therefore, some consideration should be given to the rights of the recreational beneficiaries. Another problem can occur by indiscriminate withdrawal of only the best quality of stored water through selective withdrawal outlets. Poor quality water left in the reservoir could adversely impact fishery in the pool and downstream fish and wildlife from low quality water releases.

Less than one year ago this country was in the grip of a serious drought. With all of the precipitation noted in the past few months our current problems are more related to excess runoff rather than a lack of available water. However, the drought situation was a good learning experience or at least it should have been. If we as a nation learned our lesson, we will be better prepared when the next drought arrives. I'm not sure that will be the case, as we American's seem to be slow learners when it comes to conservation practices. The drought caused the Chief of Engineers to become concerned about the role of Corps during times of deficient water supply. Some members of Congress wanted the Feds to have a stronger role in making water available to areas of short supply. However, any proposed Federal legislation that impacts on State water rights has very little chance of success. Such was the case in 1977, although some new

authorities were considered for the Corps, they were quietly put to rest to avoid any implication of infringing on state rights. Mr. Peter J. Ognibene, writing in the Washington Post recently, was very critical of the present system of water rights and the "appropriation doctrine" in particular. He was also disturbed with President Carter because he has promised that his new policies will not interfere with the way the states use Federally subsidized water. With little chance for new authorities in the area of water supply, the Office, Chief of Engineers sent out a multiple letter to Division Engineers on 10 February 1978. The subject of the letter was, "Water Control Management for Reservoir System Benefits During Droughts". The letter directed water control managers to review plans for project regulations during droughts. Wherever possible, regulating procedures are to be improved to make more effective use of storage facilities during droughts. Any changes must, of course, be within existing authorities.

Planners can be very effectively utilized in this re-evaluation of low flow regulation schemes. Their knowledge of basin needs, cost sharing requirements, legal authorities, dealing with local interests, etc. should be blended with sound water management practices to arrive at improved regulating plans. Generally, the first response to the review of low flow plans is that we are doing all that is legally possible. This response may be correct in many cases but more intensive management usually results in improved regulating procedures. Close coordination with project beneficiaries is an absolute must when contemplating changes in regulating procedures. If a project beneficiary is to be adversely impacted by a change, such as slightly less flood protection, the beneficiary must be appraised of the extent of the loss. The trade offs should be clearly displayed and if not obviously advantageous, the changed procedures will have little chance of acceptance. When properly planned and coordinated, significant changes in the prevailing water control plans can be successfully carried out. A good example of modified regulating procedures in the North Pacific Division (NPD) was the

operation, FISH FLOW 1977. This operation and FISH HAUL 1977 are described in a report prepared by NPD and distributed to field offices by the Office, Chief of Engineers. On a couple occasions the available water downstream from the Corps' Bowman-Haley project in North Dakota was so scarce that domestic needs could not be met. Emergency requests from state officials resulted in temporary releases from future water supply storage by the Omaha District Engineer.

Use of future water supply storage during the interim period until it is used by the contracting entity has been a subject of controversy over the years. Some would argue that no other purpose has a right to the storage during the interim period. However, it is obvious that the storage will serve at least one purpose, whether specifically planned or not. If held empty, it will be available for storing flood waters. If water is stored, the pool area will serve recreation interests.

Although there are no specific legal requirements to hold water in future water supply space, it has generally been agreed that this is the best practice. A major reason is that recreation facilities can be installed without concern for relocation or replacement when the storage is actively used for water supply. It also provides a convenient source of water when emergency conditions prevail such as at Bowman-Haley.

The use of future water supply storage, inactive storage, or other types of storage for emergency water supply must be carefully administered, otherwise, the Corps may be subject to severe criticism. If a community fails to provide adequate water supply facilities for its citizens and depends on the Corps to take care of them during critical times and they are accommodated, Federal laws will be circumvented. If on the other hand a community's source of water is inadequate because of uncontrollable circumstances, the Corps should take all reasonable action to relieve the immediate emergency. Long range plans may then be negotiated with the

community to provide water supply storage with normal repayment of associated project costs, if storage is available. The use of inactive storage to take care of water supply emergencies will result in complaints from recreational interests because of loss of pool level and area. However, the people using the pool for recreation are generally the same people requiring emergency water supply. In such cases the trade offs are not difficult to resolve. Other cases where different people are involved can require expert negotiating skills and hard decisions. However, water control managers would have a difficult time defending a decision that opted for water recreation over emergency water supply.

The Corps earliest water supply contract was negotiated in 1948 by the Pittsburgh District. It involved 11,000 acre feet at Mosquito Creek Reservoir in Ohio for about one half million dollars. Since that time, quite a number of contracts have been consummated by several different authorizations. There are also a few other agreements, whereby, the Corps provides water supply storage. However, these are not formal water supply contracts as are currently required. At the present time the Corps has 148 water supply agreements for storage. In many cases there is more than one agreement at a project. Thus, the total number of Corps projects involved is 91. Most of these projects are located in areas of moderate or scarce runoff, such as Texas, Oklahoma, Arkansas, etc. The smallest amount of storage contained in an agreement is 20 acre feet (AF), whereas, the largest amount is about 400,000 acre feet. There is one larger agreement for 1,300,000 AF, however it also contains storage for hydropower production. Two other items of importance are the cumulative amount of storage (almost 8,000,000 AF) and the aggregated cost of the storage (nearly \$400,000,000). These figures show conclusively that water supply is a big business for the Corps of Engineers. Information concerning the statistics of this water supply business can be obtained from the Planning Division in the Office, Chief of Engineers.

Sedimentation is a natural phenomenon which can have an important impact on water supply storage. It must be carefully monitored to ascertain

the accumulation and distribution within reservoir projects. Some parts of the Country are more prone to large sediment movements than others. Unfortunately, these are the areas where reservoirs with water supply storage are most prevalent. Unanticipated large amounts of sediment inflow can take over space reserved for water supply storage without regard to water supply contracts and their legal significance.

During the planning and design of reservoir projects, sedimentation studies must be conducted thoroughly to make proper allowances for sediment accumulation during the economic life of the project. It has been Corps practice for many years to include enough storage in each project to accommodate sediment and prevent infringement on project purposes. Technical procedures are available to make reasonable estimates of sediment inflow and its distribution. However, they are based to a large extent on past experience. Future hydrology and man's activities can drastically change estimates.

Inclusion of sediment storage, if properly distributed among project purposes, can provide a significant bonus for water supply purposes until the storage is occuppied. There is actually more storage available for use than indicated in the water supply contract. However, the possibility that more sediment can deposit in the water supply pool limits than anticipated also exists. This could mean early depletion of available storage and loss of water supply yield. In order to avoid unfair treatment of water supply users because of sediment, a new clause was recently added to a water supply contract. The action indicated in this clause should be an important consideration for all contracts where sediment could be an important factor. The clause reads as follows: "Sedimentation surveys will be made by the Contracting Officer during the term of this agreement at intervals not to exceed fifteen (15) years unless agreed to in writing by both parties. When, in the opinion of the Contracting Officer, the findings of such survey indicate a project purpose will be affected by unanticipated sedimentation

distribution, there shall be an equitable redistribution of the sediment reserve storage space among the purposes served by the Project including municipal and industrial water supply. The total available remaining storage space in the Project will then be divided among the various Project features in the same ratio as was initially utilized. Adjusted pool elevations will be rounded to the nearest one-half foot. Such findings and the storage space allocated to municipal and industrial water supply shall be defined and described as an exhibit which will be made a part of this agreement and the reservoir regulation manual will be modified accordingly."

Although techniques are available for handling normal sedimentation processes, other problems have evolved because of man's inability to effectively mitigate the adverse impacts of his activities. Unusually large increases in the inflow of sediment and other pollutants to reservoir's have resulted in some cases. This item is included in the Director of Civil Works list of policy issues which must be resolved in the near future.

Mining activities, timber harvesting, road construction, and agricultural practices have all been sources of increased sediment and pollution problems. Fisntrap lake in the Ohio River Division is probably the best or worst example of unanticipated sediment inflow caused by mining activities in the watershed above the lake. A significant loss of storage resulted in a relatively short time span from this increased sediment load. There was even a Congressional inquiry regarding reasons why the Corps had not done anything to prevent drastic increases in sediment movement. The reason was very simple, "the Corps has no authority to control watershed development". Land purchased for the reservoir was not responsible for the additional sediment.

Problems arising from mining-related chemical pollution, which originates upstream from Federal water resource projects, have significantly

affected over 50 projects. Some of the most obvious effects include reduced recreational values, degraded fish and wildlife resources, impaired water supply and metal and masonry corrosion. An interesting example of how acid mine drainage can impact on the design and cost of a reservoir project, is the Tioga-Hammond project in the North Atlantic Division. In this project two streams combine at the dam to form the reservoir. One stream has good quality water while the other is highly polluted from mine drainage. Because there was no authority available for the Corps to do work outside the reservoir area, normal inflow from the two streams had to be kept separate. Thus, costly control structures had to be provided with a reduced reservoir size for good quality water.

Two basic methods are available for correcting pollution problems connected with reservoirs that are caused by watershed activities. Generally, the least costly and more desirable method is the control of the polluting agent at its source. The other method is control of the pollutant after it reaches the reservoir area by such actions as debris basins and in-lake chemical treatment. The "Surface Mining Control and Reclamation Act of 1977", Public Law 95-87, may provide the authority to prevent future pollution of water supply reservoirs by mining activities. Review of watershed pollution abatement plans by the Corps when their projects are affected, could be the mechanism for obtaining satisfactory plans from the mining companies. The law is still too new to establish the influence which the Corps will have on changing pollution abatement plans. However, the review of such plans and recommendations for specific changes or improvements appear to be logical assignments to water resource planners. Another logical planning effort is the exploration of structural and nonstructural measures for control of sediment and acid inflows to Corps reservoirs from any source. All such measures will require economic and environmental acceptability and must be compatible with present project purposes.

A question that is beginning to appear more often as reservoir projects age is, "What will you do with the reservoirs when they fill with sediment?" There is no easy answer to the question but it won't be too many years before solutions to this dilemma will be needed. The advantages and acceptability of many alternatives will have to be investigated, particularly when loss of water supply storage is involved. Removal of sediment from reservoirs, although extremely costly, may prove to be an acceptable option when compared to the cost of other means of obtaining water supply. Thus, another task for water resource planners that may become much more prevalent in the future.

Although water supply planning efforts in the Corps have traditionally concentrated on new projects, future activities will primarily involve planning connected with existing reservoir projects. There may be other large planning efforts such as the Northeastern United States Water Supply Act but large multipurpose reservoirs are not likely to be available options. Therefore, it is imperative that the planners and water control managers cooperate to achieve the most effective use of present reservoirs for providing badly needed water supply for municipal and industrial purposes.

WATER SUPPLY IN RELATION TO QUALITY:

THE FEDERAL ASPECT

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ALBUQUERQUE, NEW MEXICO
MARCH 23, 1978

INTRODUCTION

Since the turn of the century, this Nation has recognized that an adequate supply of safe drinking water is both a basic requirement of good public health and essential to our economic growth and development. Thus, a safe and adequate drinking water supply is first in the hierarchy of water use priorities including municipal, agricultural and industrial demands.

During the last twenty years concern for water quality has focused primarily on the ambient, surface water environment. Emphasis on cleaning up the Nation's waterways has stressed the importance of recreational (swimmable) needs of our society and providing for the requirements of fish, and aquatic life, and wildlife.

More recently, drinking water quality in support of the personal uses, drinking, food preparation and bathing, has underlined the importance of water pollution control at the source and has re-established the equivalent importance of assuring appropriate levels of treatment or control to provide at least a minimum level of quality at the consumers tap.

Today all planners, regulators and managers must recognize the importance of addressing both the quantity and quality dimensions of the Nation's water resources on an integrated basis.

Water resource development in the past generally favored the quantitative aspects of the surface resource often with little concern for quality. Moreover, past planning and control efforts appear to have largely ignored the tremendous quantity potential yet qualitatively fragile ground water resource.

Future National goals, aspirations, and in fact, needs, demand attention to both instream quality and quantity and the often overlooked ground water resource which serve jointly, as the principle sources of the Nation's municipal water supply systems. As a consequence, if we are to wisely plan, manage and satisfy the multiple needs of our society, including drinking water quality, we must begin by addressing at least four contemporary issues.

QUALITY AT THE CONSUMER LEVEL

The first issue of concern is drinking water quality at the consumer level. While quantity of supply has been a reoccurring local, basin or regional issue, witness the most recent drought of 1977, the quality of drinking water has within this decade become a National issue.

In 1970 the National Community Water Supply Study (U.S. EPA) indicated that, while most Americans receive drinking water of adequate quality, many do not. In that study, conducted at a time when parameters of concern were inorganic chemicals and bacteria, quality deficiencies were frequently shown to be related to inadequate monitoring, poorly trained operators and antiquated treatment and distribution facilities evidencing potential sanitary defects.

Moreover, during the early 1970's years of research culminated in the introduction of new analytical procedures with which to begin to identify and quantify volatile organic compounds. By 1975, EPA's National Organics Reconnaissance Survey confirmed the forecasts of knowledgeable professionals: Trace concentrations of potentially toxic organic chemicals were identified in many surface sources and in an occasional ground water source. In addition, following chlorination treatment, toxics including potential carcinogens were found in "finished" municipal drinking water systems. This survey demonstrated on a National scale that the addition of the chemical disinfectant, chlorine, during the treatment process leads to the formation of the carcinogen, chloroform.

The National Community Water Supply Study and organic chemical studies led to the passage of the Safe Drinking Water Act of 1974, P.L. 93-523. The Act provides a statutory base for National drinking water standards and additional financial resources to States for water supply regulatory programs. The Act provides for research, development (including reuse demonstration), technical assistance and training.

The Nation's water pollution control efforts under P.L. 92-500, are now directed at a National goal--"zero discharge". Moreover, the Toxic Substances Control Act, P.L. 94-469, promises to prevent the manufacture of new chemicals if they are found to be potentially dangerous to the public health or the environment. These national programs and the new solid waste control efforts based on the Resource Conservation and Recovery Act, P.L. 94-500, offer promise for the future.

But runoff from field and forest, municipal runoff, spills associated with transportation accidents (truck, rail and barge), malfunctions of municipal and industrial waste treatment systems, municipal and industrial strikes and a plethora of other malfunctions of modern systems all pose very real threats to downstream users. Further, as towns become cities, a megapolis syndrome of less time and distance develops between points of discharge and points of withdrawal.

Thus, the community water treatment system provides a last line of defense for community health both now and in the future.

In direct support of this principle the National Interim Primary Drinking Water Regulations were promulgated on December 24, 1975 and July 9, 1976 and became effective on June 24, 1977. These regulations were based on the Public Health Service Drinking Water Standards of 1962, as reviewed by the statutory National Drinking Water Advisory Council, and contain maximum contaminant levels (MCL) and monitoring requirements for microbiological contaminants (coliform bacteria), 10 inorganic chemicals, 6 organic chemicals (pesticides), radionuclides and turbidity. Secondary Drinking Water Regulations were proposed by EPA on March 31, 1977.

The primary regulations are devoted to constituents affecting the health of consumers, while secondary regulations include those constituents which primarily deal with aesthetic qualities of drinking water. The primary regulations are applicable to all public water systems which regularly serve 15 service connections or 25 people and are enforceable by EPA or the States which have accepted primacy. Secondary regulations are not Federally enforceable and are intended as guidelines for the States.

To be included in the regulations as an MCL a parameter must be susceptible to simple analysis at the operating level. This recognizes that the Act intends that monitoring will be routinely accomplished by the local water system rather than by the State or EPA. Where routine monitoring is not possible, EPA has authority to issue treatment regulations.

On February 9, 1978 EPA acknowledged the synthetic organic chemical threat and printed a proposal in the Federal Register to further amend the Interim Primary Drinking Water Regulations by adding requirements for other organic chemical contaminants. The proposed amendment consists of two parts:

1. The establishment of a MCL of 0.100 mg/l for total trihalomethane (THM), and

2. Treatment with granular activated carbon or equivalent for all communities of over 75,000 population which are vulnerable to synthetic organic chemical pollution.

THE QUANTITY OF SUPPLY

The second issue of concern is quantity of supply - both now and in the future. Relatively plentiful supplies are still available at the National and basin aggregate level but, as evidenced by the ratios of withdrawal and consumption to dependable supply, there are critical short run periods where drinking water competes with much larger aggregate withdrawal demands of industry, commerce and agriculture in several regions/basins. Thus, when the quantity issue is addressed at the ASA* level, a different picture appears.

Both surface and ground water supplies are currently under stress. Regional reports on an ASA basis as part of the Water Resource Council's Second National Assessment pinpoint numerous local instances of known or anticipated quality and quantity problems in surface streams. Cycles of withdrawal from and discharge to surface waters with attendant quality deterioration from an upstream to downstream direction are typical. Moreover, despoilment as evidenced by the previously under-reported degradation and depletion of the Nation's ground water is also beginning to come into perspective.

A few statistics will serve to better focus the quantity problem as it relates to drinking water quality. The current annual average runoff, allowing for 100 BGD of consumptive loss, is 1200 BGD. Current and future withdrawals and estimated consumptive losses show that as a Nation we are not running out of water but there is cause for concern.

As shown in Table I, freshwater use at 338 BGD in 1975 is projected to decline to 306 BGD by the year 2000 while total consumption will increase from 107 BGD to 134 BGD. Thus, major shifts are expected as a function of use. Domestic commercial, and mineral withdrawals will rise in proportion to population increases. Agricultural, steam electric and manufacturing withdrawals decline. Concurrently, as production increases by 6 fold, consumptive losses associated with steam electric and manufacturing uses rise dramatically as industry shifts from once thru cooling to multi-recycling due to the pressures of ambient stream quality requirements.

*Aggregate Sub-Area

Table I
ANNUAL WATER REQUIREMENTS FOR OFFSTREAM USES
AVERAGE YEAR*
(MILLION GALLONS PER DAY)

Type of Use	Total Withdrawals			Total Consumption		
	1975	1985	2000	1975	1985	2000
Agriculture						
Irrigation	158,743	166,252	152,722	86,391	92,820	91,821
Livestock	1,912	2,233	2,551	1,912	2,233	2,551
Steam Electric	88,904	94,855	80,052	1,418	4,062	10,544
Manufacturing	51,210	23,664	19,661	6,049	8,893	14,686
Domestic						
Central	21,164	23,983	27,918	4,976	5,065	6,638
Non-Central	2,092	2,321	2,401	1,294	1,409	1,439
Commercial	5,530	6,048	6,732	1,109	1,216	1,369
Minerals	7,055	8,832	11,328	2,196	2,777	3,609
Public Lands and Other**	1,866	2,162	2,461	1,235	1,460	1,730
Total, Freshwater	338,455	330,313	305,790	106,561	120,524	134,441
Total, Saline	59,747	91,239	118,815			
TOTAL	398,201	421,552	424,605			

*U.S. Water Resources Council, Part III (Draft), October, 1977.

**Public lands, fish hatcheries, and miscellaneous uses.

From these data we can quickly conclude that there will be about a 10 percent reduction in return flow which means less dilution particularly during periods of low stream flow. Moreover, the cyclic "head-to-mouth" reuse of water will lead to increasing levels of conservative pollutants in the Nation's streams and potential problems for aquatic life and the downstream drinking water consumer. For instance, it is important to note that our most sophisticated mass-spectrograph-gas-chromatograph analyzers are only capable of identifying 10 percent of the mass of organic compounds known to exist in representative samples. The other 90 percent, trace quantities of non-volatile organics, have neither been identified nor typed relative to chronic disease potential.

Thus, a reduction in forecasted National or regional withdrawals, which will make newspaper headlines, is not a basis for complacency. Planners will need to redouble their efforts particularly at the basin and local level to assure that both quantity and quality concerns are identified and addressed in an intelligent manner.

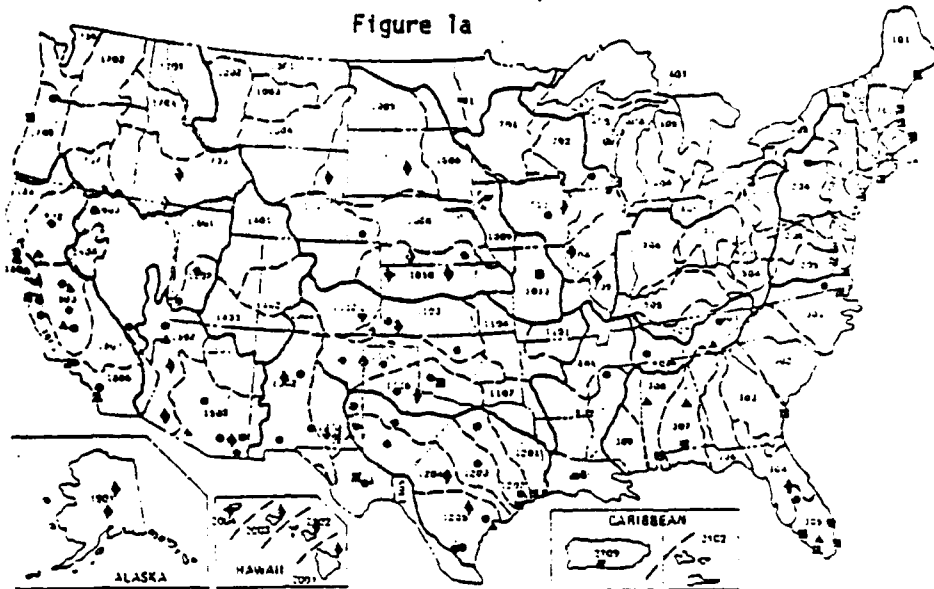
GROUNDWATER MANAGEMENT

Historically, ground water has been perceived as a separate entity from surface water. Further, ground water quality and quantity have been primarily regulated or managed separately, if at all, by local entities and a few States only after they were confronted by imbalances, either depletion or degradation.

As a consequence of the lack of Government stewardship and public awareness, a dichotomy exists today. From a quantity standpoint, an estimated stock of 65 quadrillion gallons of ground water is available within a few thousand feet of the surface. In 1973 the National Water Commission estimated that the volume of ground water in storage to a depth of one-half mile is roughly equivalent to the total of all recharge during the last 160 years. But 80 percent of the Nation's total fresh water withdrawals are satisfied by surface waters, thus, there is a gross lack of recognition and wise use of the ground water resources in large areas of the country.

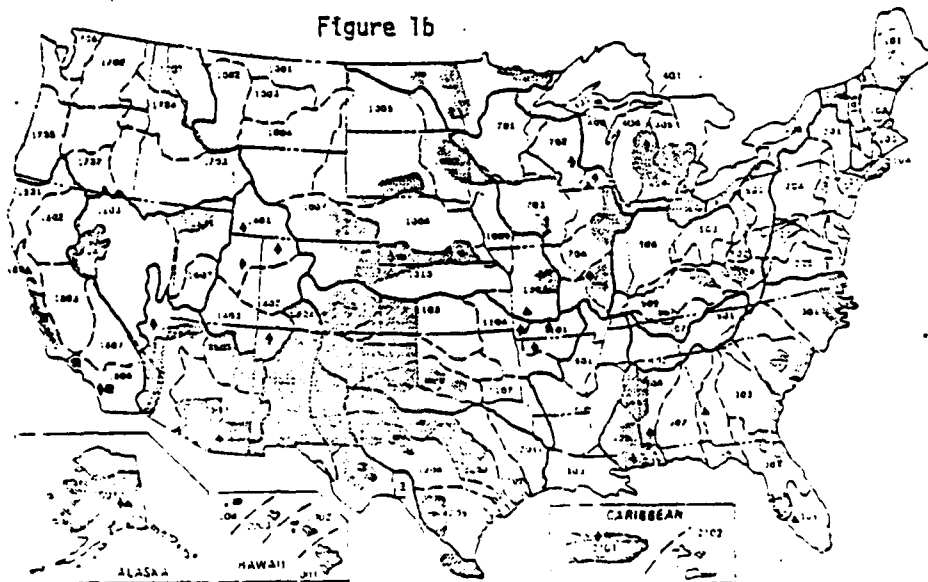
Conversely, past patterns of economic growth and associated ground water development have not matched the natural distribution of ground water, which frequently creates an imbalance within and between hydrologic basins (Figure 1A). Depletion is evidenced by falling ground water levels, increasing pumpage and treatment costs, land subsidence, surface fissures and salt

Ground Water Depletion
Figure 1a



- Legend
- Areas with Greatest Total Impact
 - Areas that have groundwater depletion
 - Location of Specific Impacts
 - Mining of groundwater that threatens the water source
 - Withdrawal that causes subsidence and ground water
 - Withdrawal that causes salt water intrusion and fresh water depletion

Ground Water Contamination
Figure 1b



- Legend
- Areas with Greatest Total Impact
 - Areas that have groundwater contamination
 - Areas that have water pollution
 - Salt and other chemicals
 - Hazardous and petroleum
 - Contamination resulting from mining of water from the sea
 - Contamination resulting from extraction of water from the sea
 - Salt and other chemicals
 - Hazardous and petroleum
 - Contamination resulting from mining of water from the sea

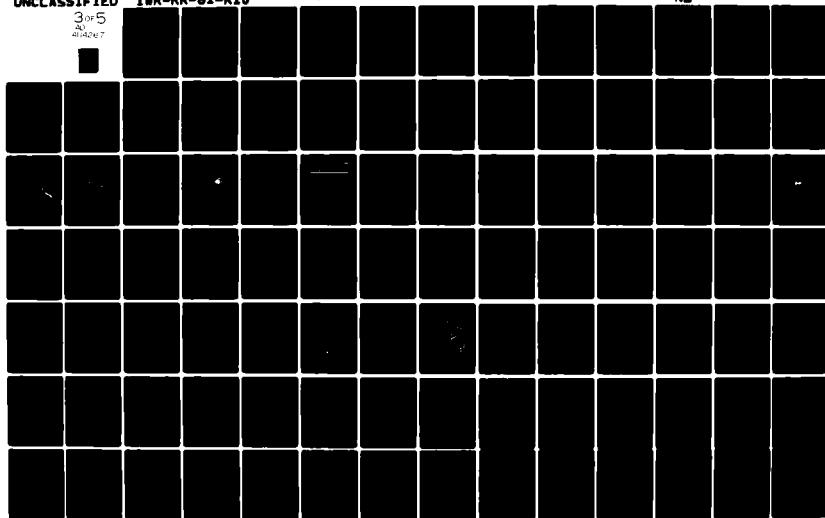
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water intrusion into fresh water aquifers. Moreover, municipal-industrial-commercial concentrations exacerbate waste disposal problems. With recent priorities aimed at preventing or minimizing dischargers to streams many wastes are now being applied to or injected into the ground. As a consequence, many current practices jeopardize the quality of the ground water resource. Thus, State/Regional study teams recently reported ground water pollution problems in 75 of 106 ASA's, (Figure 1B).

Ground water quality degradation is caused by the downward percolation of pollutants associated with various municipal, agricultural and industrial activities. These practices pose substantial economic and public health problems. On an economic scale, pollution threatens the current annual investment of \$3 billion per year to drill 700,000 wells for domestic, agricultural, industrial and municipal use. From a public health perspective, it must be noted that about half of the Nation's population utilizes ground water for drinking or other domestic purposes with little or no treatment, and 40 percent of irrigated agricultural requirements are satisfied by ground water. In many areas of the country, ground water is the only practical drinking water source.

The only effective means for protecting ground water quality and minimizing billions of dollars of future treatment costs to municipalities, industry and agriculture is to avoid depletion and to prevent pollution by regulating potential contamination at the source(s).

On this basis it should be noted that existing Federal and State programs address elements of good management and many of the classes of potential contamination of ground water, but they do not provide comprehensive protection or conjunctive management for quantity and quality. Clearly, ground water requires a new National priority. In satisfying this need, the interrelationships between ground and surface water, both quantity and quality, must be addressed.

PLANNED AND MANAGED REUSE

The fourth issue derives from the fact that as planners, regulators and managers, we must recognize an increasing trend toward multiple reuse of water. This can be a double edge sword.

As a conceptual and practical matter, reuse is a desirable conservation measure when viewed from a quantity standpoint. As a matter of protecting the public health, we must make haste slowly with respect to drinking water quality.

Reuse can take several forms. Unplanned reuse occurs when towns and industries on interior watercourses extract and discharge water progressively from "head-to-mouth." Planned reuse can occur within an industry where water is recycled through a variety of inplant operations. Planned reuse also can occur through the deliberate use of municipal wastewater treatment effluents where lower quality waters are adequate, e.g., industrial cooling and golf course watering. In this sense, highly treated wastewaters from advanced wastewater treatment may ultimately serve in the future as new "raw" water sources for domestic purposes.

Reuse of water, both planned and unplanned, introduces many complexities. Public health related quality considerations will require substantial analysis and research prior to broad, direct full-scale application of this concept in so far as drinking water requirements are concerned.

The principle concerns in the use of reclaimed wastewater for drinking are the potential adverse affects of small amounts of organics in the water. The volume, types, and associated long term health effects of the variety of constituents which may be found in small concentrations in municipal wastewater effluents is largely unknown. The Drinking Water Regulations, minimum standards applicable to finished waters at the tap, were originally derived and intended to apply to raw water from essentially uncontaminated source. Presently, there are no drinking water standards or criteria for the planned direct reuse of municipal wastewater for potable purposes. In this connection, the National Academy of Sciences recently concluded that the currently applicable bacteria standards are not sufficient to protect public health from water containing several percent of fresh sewage effluent.

To satisfy public health concerns relative to the reuse detailed analysis of various options including recycling thru industrial and commercial users, dual systems and then direct recycling need to be thoroughly investigated. From a drinking water perspective this will require substantial investments in research and development to identify various reuse approaches, to identify constituents of concern, to define health effects information (dose-response), to

establish the monitoring requirements (regulatory and operational) and to define economically feasible treatment and distribution (such as dual distribution systems) alternatives.

Conclusion

Having identified four issues one might conclude that I view the future as bleak. This is not the case. The future is full of challenges providing planners with opportunities to develop innovative solutions in an era where the interdependence of quantity and quality is recognized. Moreover, public awareness will create a continuing priority for sensible, professional solutions to what are often perceived as highly complex technical, legal and institutional problems at the community level.

Clearly, the nation is maturing and in the last twenty years has come to realize that our resources are not inexhaustible, but they are fragile. Droughts have impacted all major sections of the country sensitizing the population at large to the quantity issue. The Congress, responding to an informed constituency, has provided a wealth of new statutes which will challenge Federal agencies, and the States, as well as local entities in the name of quality.

In response to the new public and political appreciation of both quality and quantity we must all recognize, first, that it is no longer sufficient to address future quantitative needs of municipalities and industries. Each alternative source of supply will require quality investigation relative to the cost of treatment and monitoring once delivered to the community where new sources of supply are needed. Moreover, cities and towns are beginning to identify chemicals deficiencies (MCL violations) and are learning about their share of estimated National treatment cost of \$1.8 billion to meet the basic Interim Primary Drinking Water Regulations and \$500 million to meet the recently proposed organic chemical regulations. As a consequence, cities and towns will be approaching planners seeking alternative solutions to chemical quality problems even in those situations where quantity of supply is not at issue. To be responsive to these concerns planners and regulators will need to learn a whole new chemical contaminant language along with related treatment technology and associated costs.

Secondly, we must be prepared for the reality that current forecasts projecting a reduction in aggregate withdrawals during the next twenty years do not necessarily bode well for either quantity or quality concerns at the basin or local level. Coming as a result of increasingly stringent water pollution control requirements, recirculation and land treatment will become a widely practiced reality. Efforts to mitigate the effects of pollutants including the conservation and recycling of nutrients will concurrently increase consumptive losses. Thus, there will be not only less flow to support withdrawals, but less natural dilution particularly during future droughts. With less dilution available there will be a rise in the concentration of conservative pollutants posing potential threats to downstream drinking water intakes as well as fish and aquatic life.

Third, we must all give ground water more attention. Here the challenge is twofold:

1. how to better plan and wisely use the quantity and quality dimension of ground water where available in bountiful supplies, and;
2. how to conserve and protect this natural resource where stress has developed.

Fourth, we must find a way to depolarize the reuse issue. Pending the completion of the research agenda which I personally believe is necessary, the best available sources of raw water should be reserved for at least those community water uses which are health sensitive--drinking, cooking, and bathing. These functions seldom account for more than 40-50% of aggregate per capita demand. Thus, in the worst case situations there is still ample opportunity to recycle so called "gray water" within the community for landscaping, car washing and a host of less sensitive requirement via dual system.

Finally, as we prepared for the next twenty years, we should realize that neither quantity nor quality are ends in themselves. When National, basin and local issues arise, the public has a right to expect that planners and regulators will identify realistic, workable alternatives rather than arguments based on alleged irreconcilable conflicts. Acknowledging that neither planning nor regulation are risk-free, a way must be found to move towards conjunctive planning and management of quantity and quality including the priority for drinking water quality at the consumers tap.

WATER SUPPLY
AND
QUALITY PLANNING

QUALITY PARAMETERS IN WATER SUPPLY PLANNING

A Talk Presented at the Training Course
On Water Supply Planning, Sponsored by
the Corps of Engineers' Institute for
Water Resources, in Albuquerque, N.M.,
March 21, 1978

by Eric D. Bovet
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SUMMARY

1. The Planner's Options When Designing for Water Supply Quality

The provision of an adequate community water supply is dependent upon where, when, how abundantly, and how dependably nature bestows and replenishes water sources on the surface and underground. Within limits, nature's bounties may be stretched or supplemented, but even the Corps of Engineers must have something to play with. A similar limitation upon water quality does not seem to exist. Technology is available today for making practically any water fit for human consumption. Where minimal treatment at reasonable cost is insufficient to meet specified or desirable water quality levels, it may be necessary to have recourse to water softening, secondary or tertiary treatment, and/or one of the desalting processes.

Thus, it would appear that, while water cannot yet be extracted from the air and fresh sources are limited in quantity, water quality can usually be bought at a price. This roughly sets the stage for determining the options of the water supply planner concerned with quality.

What are these options? The simplest case is that of a single adequate water source with a constant water quality, requiring routine treatment to meet desired water quality goals. The decision is only one of whether or when to administer the treatment. But as soon as stochastic variations over time in raw water flow and quality are introduced, options multiply. Water quality should be expressed in percent of the time it is expected to comply with given levels.

Two or more water sources again increase the options. But where the attainment of desirable water quality exceeds in complication all water quantity problems is in the infinite variety of water contaminants, their concentrations, chemical compounds, and combinations. To these must be added thermal and radiological pollution.

Water purification is often expressed in percent removal of specific substances. These percents may vary considerably depending on the original concentration. What is still lacking is a comprehensive price list for removing specific contaminants -- not by percent removal, but in terms of residues, in parts per million, acceptable in various planned water uses.

Because options are infinite, choices are difficult unless some guidelines are followed. For example, economic theory states that, for efficiency, purification should be continued until the marginal cost equals the marginal benefit. Costs can perhaps some day be established. Benefits are related to tolerances to given concentrations of given contaminants by given organisms in given water uses. Some tolerances are quite elastic. How much healthier is an individual drinking soft water than one drinking hard water over a given number of years? Tolerances are difficult to quantify. The penalty for exceeding given tolerances is not well known. Critical water quality parameters in various uses are yet to be listed.

This illustrates some of the difficulties faced by water supply planners when they come to grips with the problem of water quality in water supply. Described below are five economic techniques for solving water quality problems, for integrating water quantity and quality, and for optimizing the results.

2. The Economist's Contribution to the Planner in Integrating Water Supply Quality with Quantity, and Optimizing the Combination

a. Water Quality Models

A number of water quality models have been developed. The most comprehensive of these is the dynamic river basin water quality model designed by W. W. Waddell et al under the sponsorship of Battelle's Pacific Northwest Laboratories. This is a cluster of partial models integrated into a more complete system, called EXPLORE I.

Existing models were used for seven parameters: Algae, BOD, DO, N, P, TOC, and toxic compounds. These were supplemented by additional parameters to simulate the essential characteristics of water quality. The model was used to predict water quality changes in the Willamette River Basin in Oregon. Actual data conformed well to predictions.

b. Optimal Raw Water Purification

Two problems invite the attention of water supply planners. The first is the optimal degree to which two raw water purification processes should be combined: Raw water pretreatment through instream reaeration, versus extra conventional treatment plant purification.

The solution involves the computation of marginal costs of both purification methods, and the determination of the level of instream pretreatment that minimizes the aggregate daily purification cost.

The second problem of this type is that of optimal water supply purification, involving not two treatment processes, but two water sources. A community has a water supply of 10 mgd with 500 ppm of total dissolved solids. An incremental 5 mgd is needed. The only available water source has 3000 ppm of TDS. The community plans to build a distillation plant to demineralize a portion of the water supply and blend the product water with more water from either source. The resulting water should be of a quality that minimizes costs plus the damages of using substandard quality water .

To solve that problem, a distillation cost schedule can be developed from a three-point cost curve related to three orders of magnitude of plant capacity. A damage schedule can be established in a similar manner.

From it may be derived a benefit schedule. Both cost and benefit schedules, tied to quantities of water distilled in 1 mgd increments, are further developed to yield incremental, as well as marginal, costs and benefits. When linked to salinity levels, the figures showed that marginal costs equaled marginal benefits at 7.5 mgd distilled at a salinity of 250 ppm of TDS after blending. Damages plus costs were lowest at the same levels.

c. Optimal Water Supply Allocation from Multiple Sources
With a Single Quality Parameter

A community has an existing water supply of 40 mgd with a salinity of 500 ppm of TDS, and needs additional water. Two freshwater sources are limited in quantity and are both of substandard quality; wastewater can be reused upon renovation; sea water is accessible. Distillation would be applied to the sea water; all other sources would use a membrane desalting process. The options consist of 5 total water quantities with 7 salinity levels, for a total of 35 alternatives. Which is optimal?

This problem is interesting in that different solutions were arrived at on the basis of different criteria: net benefits, versus benefit-cost ratios, marginal costs and marginal benefits, least damages plus costs. Trade-off opportunities existed between additional quantities and enhanced quality. Compromises appeared likely to be sought.

d. Optimal Water Supply Allocation from Multiple Sources
With Multiple Water Quality Parameters

When more than one quality parameter is considered, more sophisticated techniques are necessary. However, important sacrifices must be consented.

The first of two problems omits the possibility of upgrading water quality. Given k alternative raw water sources, each with a known maximum supply, each containing a given concentration of up to M types of impurities and available at a known cost per gallon -- minimize the cost of providing a given total amount of water with a maximum allowable concentration of each of the M impurities.

This is a relatively simple linear programming problem easily solvable on any computer. It is assumed, however, that impurities in the water are non-reactive and, which is an even more unrealistic oversimplification, that there are no economies of scale in water works.

The second technique is more comprehensive and less restrictive. It includes provisions for upgrading water quality, and permits direct optimization without iteration of computer runs. All water uses within a given area are catalogued, and water quality standards and effluent quality determined for each use. Demands exceed the primary supply. Costs are known for upgrading one user's waste for the use of another, and for obtaining primary, imported, and desalted water. Also known is the amount of water required and wastewater generated by every class of water user.

The least cost method of satisfying all quantitative and qualitative water demands was obtained through linear programming.

3. Conclusion

In planning for quality water supply, advanced economic techniques should be supplemented by a good deal of imagination. Options are infinite in number, and sometimes miracles can be wrought at astoundingly low cost.

QUALITY PARAMETERS IN WATER SUPPLY PLANNING

by Eric D. Bovet
Consulting Economist

TABLE I

OPTIMAL UTILIZATION OF TWO RAW WATER TREATMENT PROCESSES

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Degree BOD	Instream Reaeration		Treatment Plant Costs		Stream +	
Removal	Units	Costs	Cumulative	Remaining	Plant Costs	
%	#	\$/yr	\$/day	\$/day	\$/day	\$/day
0	0	0	0	0	1,313	1,313
35	3	41,500	114	457	856	970
88	12	129,600	355	840	473	828
95	18	182,500	500	961	412	912
97	22	216,500	593	1,313	0	593

TABLE II

WATER SUPPLY ALLOCATION WITH SINGLE QUALITY PARAMETER

Available Sources

	Quantity (mgd)	Quality (ppm of TDS)
Existing water supply	S = 40	s = 500
Add'l freshwater source I	F1 = 24	f1 = 1,200
Add'l freshwater source II	F2 = 12	f2 = 1,000
Renovated wastewater	w = 30	w = 850
Distilled sea water	D = infinite	d = 50

Optional Requirements

R = 60	r = 800
65	700
70	600
75	500
80	400
	300
	200

TABLE III

OPTIONS AMONG OPTIMAL SOLUTIONS

	<u>Quantity</u> (mgd)	<u>Quality</u> (ppm)	<u>Net Outlay</u> (\$/day)	
1. <u>Maximum Net Benefits:</u> \$16,000/day	80	300	12,400	
2. <u>Maximum Benefit-Cost Ratio:</u> 2.34	60	600	2,560	
3. <u>Marginal Benefits = Marginal Costs:</u>	60-65	300	11,790	
		(700	0	
	70-80	(600	1,940	
		(300	11,800	
4. <u>Minimum Damages + Costs:</u> \$15,870/day	60	300	11,970	
5. <u>Trade-Off Opportunities Between Quantity and Quality:</u>				
a. Based on	<u>Net</u>			
Net Benefits	<u>Benefits</u>			
	(\$/day)			
	9,540	65	200	17,760
	9,575	75	400	9,550
b. Based on	<u>Desalting</u>			
Desalting Costs	<u>Costs</u>			
	(\$/day)			
	5,100	60	500	5,100
	5,100	75	600	2,100
c. Based on	<u>Damages +</u>			
Damages + Costs	<u>Costs</u>			
	(\$/day)			
	18,660	80	200	18,660
	18,600	60	400	8,700
6. <u>Likely Compromise:</u>	80	500	5,200	

TABLE IV

STATEMENT OF THE OPTIMAL WATER SUPPLY ALLOCATION PROBLEM: MULTIPLE
SOURCES AND MULTIPLE WATER QUALITY PARAMETERS -- NO WATER TREATMENT

$$\text{Minimize } \sum_{i=1}^N q_i K_i$$

$$\text{Subject to: (1) } \sum_{i=1}^N q_i \geq T$$

$$(2) \quad q_i \leq Q_i \quad (\text{all } i, i = 1 \text{ to } N)$$

$$(3) \quad \sum_{j=1}^M c_{ij} q_i / T \leq C_j \quad (\text{all } j, j = 1 \text{ to } M)$$

$$(4) \quad q_i \geq 0 \quad (\text{all } i, i = 1 \text{ to } N)$$

Where: Q_i = maximum yield of source i (gpd)

c_{ij} = concentration of impurity j in water from source i

T = total amount of water required (gpd)

K_i = cost of water from source i (\$/gpd)

C_j = maximum allowable concentration of impurity j in the final blended water

q_i = amount of water to be taken from source i (to be determined, gpd)

TABLE V

STATEMENT OF THE OPTIMAL WATER SUPPLY ALLOCATION PROBLEM: MULTIPLE
SOURCES AND MULTIPLE WATER QUALITY PARAMETERS, WITH WATER TREATMENT

$$\text{Minimize } \sum_{i=1}^M \sum_{j=1}^N c_{ij} x_{ij}$$

$$\begin{array}{ll} \text{Subject to: } (1) & \sum_{j=1}^N x_{ij} \leq A_i \\ & \left. \begin{array}{l} (2) \sum_{i=1}^M x_{ij} \geq B_j \\ (3) x_{ij} \geq 0 \end{array} \right\} \begin{array}{l} i = 1 \text{ to } M \\ j = 1 \text{ to } N \end{array} \end{array}$$

Where: c_{ij} = cost of upgrading the quality of water from source i for use by j

x_{ij} = amount of water from source i used by user j (to be determined)

M = number of sources

N = number of users

A_i = quantity of water available at source i

B_j = amount of water required by user j

THE NORTHEASTERN UNITED STATES
WATER SUPPLY (NEWS) STUDY

by

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U.S. ARMY CORPS OF ENGINEERS

Presented At: A Conference on Water Supply and Water Quality Planning
10 December 1975
Atlanta, Ga.

Sponsored By: U.S. Army Corps of Engineers
Institute of Water Resources

OUTLINE

1. Introduction
2. The Legislation
3. Areas Studied
4. Planning Objectives
5. Types of Projects Considered
6. Financing
7. Long Range Investigations
8. Institutional Arrangements

1. Introduction

During the early and mid years of the 1960's a severe drought hit the northeastern section of the United States. As a result, the water supplies of 14 million people or approximately 1/3 of the population living in this part of the country were placed on restriction. The United States Congress responded by passing Public Law 89-298 on 27 October 1965 which authorized the Secretary of the Army acting through the Corps of Engineers to undertake the Northeastern United States Water Supply Study. That study which is referred to as the NEWS Study is nearing completion.

2. The Legislation

There are four statements in the authorizing legislation for the NEWS Study that I would like to bring to your attention today. The first is: "Congress recognizes that assuring adequate water for the great metropolitan centers of the United States require(s) the Federal Government to assist in the solution of water supply problems." That is significant in that it directed the attention of the Corps of Engineers to the problems of metropolitan areas and not river basins. In addition this statement indicates the Congressional recognition of the need for Federal assistance.

The second is that the plans to meet the long range water needs of the Northeastern United States "may provide for the construction, operation and maintenance... of a system of major reservoirs..., major conveyance facilities ..., and major purification facilities." This is significant in that it is indicative of the type of projects Congress anticipated would be recommended for Federal authorization.

The third is that "such plans shall provide for appropriate financial participation by the States political sub-divisions thereof and other local interests." This is significant in that the Congress was allowing the opportunity for a recommendation to be made with regard to cost sharing in water supply projects.

The fourth is that "the Secretary of the Army acting through the Chief of Engineers shall construct, operate and maintain those reservoirs, conveyance facilities, and purification facilities which are recommended." It is the interpretation of the Corps of Engineers that the Congress did not intend the Corps to become one of the nation's largest water supply utilities. Therefore, the Corps has interpreted the word "shall", in the foregoing statement, to mean may.

3. Areas Studied

The authorizing legislation established the study area as that section of the northeast from Maine through Virginia which contains all of the drainage area flowing either into the Atlantic Ocean, into Lake Ontario, or into the St. Lawrence River. Contained within these boundaries are 31 areas which either exist as Standard Metropolitan Statistical Areas, as defined by the Bureau of the Census, or have the potential of becoming a Standard Metropolitan Statistical Area by the year 2020. These metropolitan areas were the focal point of the NEWS Study.

It was recognized early in the study that the size and imminence of the water supply problem would vary throughout the 31 areas. Therefore, it was decided to put most of the NEWS effort into those metropolitan areas that either have a large water supply deficit or would develop one by the year 1980. A reduced study effort would be undertaken for those metropolitan areas

with small deficits or deficits more distant in time. The urgent areas of the northeast, that is those areas with large and imminent deficits, were identified as being the eastern Massachusetts-Rhode Island area centering around greater Boston, the New York Metropolitan area containing northern New Jersey and Western Connecticut as well New York City and surrounding New York counties, and the Washington Metropolitan area containing the District of Columbia and surrounding counties in Maryland and Virginia. The remaining areas in the Northeast were identified as less urgent and therefore did not receive as intense a study effort.

For the three urgent areas considerable effort was expended in examining water supply demands, developing alternative water supply programs phased to the year 2020, and focusing on an early action project for Federal authorization. For the less urgent areas a preliminary review was made of the yields of the current water supply systems; yields were matched against projected water supply demands to forecast the size and timing of future water supply deficits, should a drought of the 60's reoccur; and the major sources of water supply available to these areas were described. More detailed planning is left to the future, after the NEWS report is completed.

3. Planning Objectives

In conducting the NEWS Study we have talked considerably to agencies, groups and individuals to determine what objectives should be used in developing water supply plans. What we have heard boils down to the following.

In designing water supply plans we have been asked to recognize:

1. The minimization of financial Cost.
2. Reliability.
3. Flexibility.
4. Timeliness.
5. Environmental Quality.
6. Regional Focus.
7. Equity.
8. Impact on Growth.

We have tried to design solutions with these objectives in mind but nowhere have we found it possible to meet all of them with any one plan. Rather, alternative plans have been prepared which relate to various mixes of these objectives.

5. Types of Projects Considered

The series E projection for population and economic activity made by the U.S. Department of Commerce, Bureau of Economic Analysis, for the United States and the various sections of the country were the basis for determining future water supply demands. These projections are considered to be moderate and are technically defined as those projections which aim at a replacement level fertility growth rate. The repertoire of projects considered in formulating plans to meet water supply demands forecast in accordance with these projections included the following.

Non-structural projects included:

- a) Considerable Industrial reuse of water in those areas showing a current heavy industrial water usage. The major motivation behind the achievement of such industrial reuse would be the implementation of the requirements of the Water Quality Amendments Act of 1972, Public Law 92-500.

b) Water saving fixtures and appliances, and water metering for inclusion in local ordinances.

c) Water pricing. In the final analysis this did not appear to be an effective mechanism for controlling domestic water demand unless prices were increased in multiples of 100%. Such price increases raise questions of equity that it was not thought legitimate to deal with in a water supply study.

d) Water use restrictions were considered to be effective for short periods of time particularly for those metropolitan areas that do not have any sizable storage facilities with which to meet peak fluctuations in water demand. Long term restrictions on water use whether mandatory or voluntary are most properly reserved as the first step to take when the design drought for a water supply project is exceeded. This would then be the first step in a contingency program.

The structural or hardware type of projects considered included the following:

- (a) Interbasin transfers of water
- (b) Skimming of high river flows
- (c) Local pumped storage reservoirs
- (d) Major wellfields
- (e) Large reservoirs
- (f) Water supply system interconnections
- (g) Indirect wastewater reuse

In preparing the various water supply plans for the northeast we have recognized that small scale demonstration projects could be helpful in overcoming both technical and social uncertainties connected with developing various sources of water. As a result we have recommended, and Congress has

authorized, a one million gallon per day pilot water treatment plant to determine whether or not technologically advanced treatment processes can be used to make potable water, continuously, out of the polluted Potomac Estuary. We are also completing a study of a possible one half million gallon per day demonstration project in which land treatment of wastewater would be investigated as a way of partially managing the groundwater aquifer underneath Long Island, which is east of New York City. Whether or not this will actually be recommended as a demonstration project is not certain at this time.

6. Financing

The financing arrangements considered for each water supply plan and its component projects followed two separate paths. The first was based entirely on local financing since water supply has traditionally been a local responsibility and financed at the local level. The second path was based on 100% capitalization of projects by the federal government, or some other extra local agent, with complete repayment of the capital cost over time.

Under the first path of local financing, revenue anticipation notes would be issued to pay costs during the construction period. These notes would be paid off with a bond issue which in turn would be paid off at 6 1/4% over a 35 year period, assuming a more favorable bond market than exists today.

Financing using the second path, which calls for 100% capitalization by either the federal government or some other extra local agent, was calculated on the basis of complete repayment of capital costs by local interests at 4.371% over a 50 year period. Repayment would begin within 10 years after completion of a project or when water from a project is first used. The Treasury Department, which sets the interest rate,

has within recent months increased the 4.371% used in our calculations to 5.116%.

The second path, or extra local financing, is currently authorized for use by the Corps of Engineers in financing water supply storage that is made part of a multiple purpose reservoir project. In 1975, a NEWS Study recommendation was made that this financing be applied to two single purpose water supply projects, namely two diversion tunnels, to serve the Boston metropolitan area.

Regardless of project financing arrangements, all project costs are allocated to the various utilities in proportion to the safe yield they receive from a project.

7. Long Range Investigations

In addition to the three urgent areas of Eastern Massachusetts-Rhode Island, New York and Washington, there are twenty-eight other metropolitan areas in the northeast that have been examined as part of the NEWS Study. Five of them show a water supply deficit by the year 1980, but only one, Norfolk Virginia has a critical need for developing an additional source of supply. Continued planning for this water supply problem is being provided by the Norfolk District of the Corps of Engineers in its comprehensive study of the Chowan River basin. The other four areas: Utica-Rome, New York; Altoona, Pennsylvania; Williamsport, Pennsylvania; and Lynchburg, Virginia; should have sufficient water by the year 1980 but will require modification in either their existing treatment, pumping, or transmission system. These problems are within the capability of the local interests concerned.

All other areas show longer range problems developing. Therefore, further studies for these areas are not contemplated for inclusion in the final report of the NEWS Study.

8. Institutional Arrangements

In formulating a position on institutional arrangements, the Corps of Engineers has adopted two guidelines:

1. The Corps does not propose to recommend that the federal government own or operate water supply projects. This is consistent with our interpretation of the Congressional intent behind the word "shall" as I mentioned earlier in the speech.

2. The Corps does not propose to recommend any change in the ownership of existing water supply systems.

Given these guidelines our position on institutional arrangements is that State and local interests review the information available to them as well as the studies we have conducted on the federal role in water supply, the state role, and the local role; the use of authorities; the use of compacts and commissions; and the use of quasi-public corporations to determine how they, the state and local interests, might wish to own and operate any water supply project authorized by the Congress. The Corps would then recommend authorization contingent upon the implementation of such an institutional arrangement.

WATER SUPPLY PLANNING EXPERIENCE
WASHINGTON, D.C., AREA*

by

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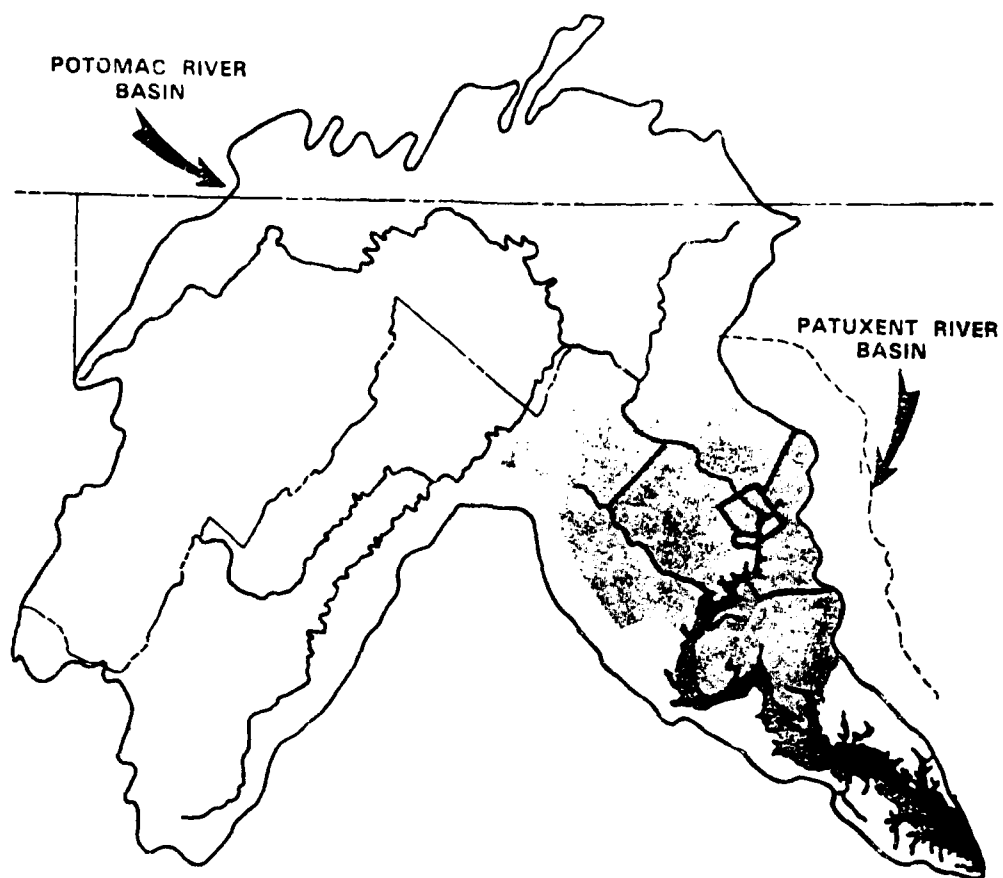
The Metropolitan Washington Area (MWA) encompasses land and water in the State of Maryland, Commonwealth of Virginia, and the District of Columbia. It covers 2,800 square miles and consists of Montgomery, Prince Georges, and Charles Counties in Maryland; the District of Columbia; the cities of Falls Church, Fairfax, and Alexandria, and the Counties of Loudoun, Fairfax, Prince William, and Arlington in Virginia as shown in Figure 1.

The MWA deserves special consideration because it is the Nation's Capital, a regional center, and because of the magnitude of its water supply problems. The MWA in 1970 was the seventh most populous Standard Metropolitan Statistical Area (SMSA) in the Country with a population of 2.9 million persons.

The largest single water supply source within the MWA is the Potomac River which has an average discharge of 7,000 mgd at Washington, D.C. Because of the unregulated nature of the river, (there are no major dams) flows fluctuate widely around the average. The highest recorded flow at Washington, D.C., exceeded 300,000 mgd in 1936, the lowest recorded flow was 388 mgd which occurred in September of 1966. The highest demand placed upon the River was 448 mgd in July 1974, fortunately the low flow and highest demand events did not occur simultaneously. The other

* The paper presented at the "Economic, Social, and Institutional Aspects of Water Supply Planning" training course in Albuquerque, N.M. 20-23 March 1978.

LOCATION OF METROPOLITAN WASHINGTON AREA



BOUNDARIES OF THE METROPOLITAN WASHINGTON AREA

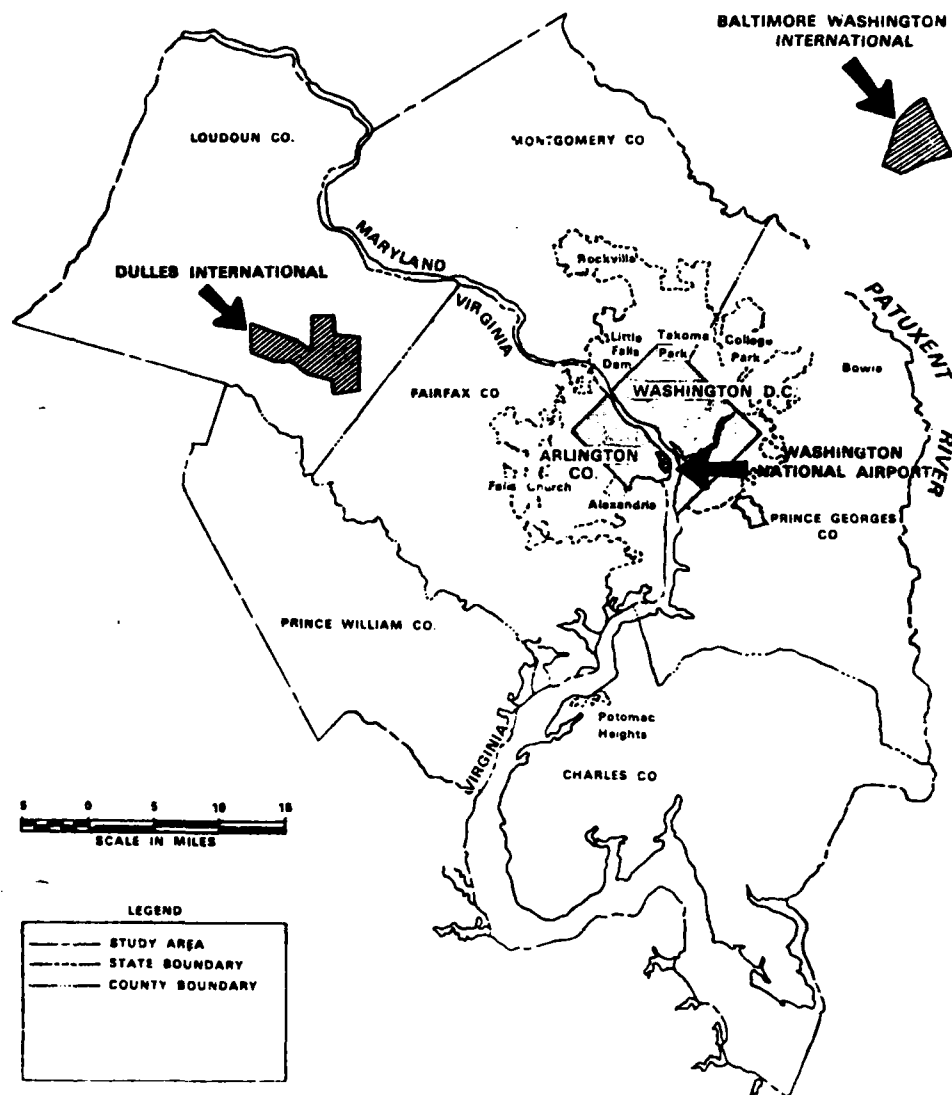


Figure 1

primary sources of water are the Patuxent River Basin, Occoquan Creek watershed, and limited groundwater. Both the Patuxent and Occoquan are controlled by major impoundments.

The MWA is currently served by 29 water supply systems ranging in size from less than 1 mgd to several hundred mgd. Ninety-six percent of the raw water for the MWA comes from rivers and creeks. The Potomac River provides 67 percent; the Patuxent River, 14 percent; the Occoquan Creek, 13 percent; and Goose Creek, 2 percent. The other 4 percent is groundwater.

The total treatment capacity of all water supply systems in the MWA, on an average day is over 600 mgd. On a maximum day basis, the total treatment capacity is almost 900 mgd. The three largest water supply facilities, furnishing about 90 percent of the total water requirements of the MWA, are the Washington Aqueduct Division (WAD) operated by the Corps of Engineers, the Washington Suburban Sanitary Commission (WSSC), and the Fairfax County Water Authority (FCWA). Figure 2 shows the major water suppliers and their respective service areas.

The WAD withdraws water from the Potomac River at both Little Falls and Great Falls. After treatment the finished water is transferred to water retailers in the service areas of the District of Columbia, Arlington, Falls Church, and part of Fairfax County. Distribution of water within these areas is the responsibility of local jurisdictions.

MAJOR WATER SUPPLY SYSTEMS - METROPOLITAN WASHINGTON AREA

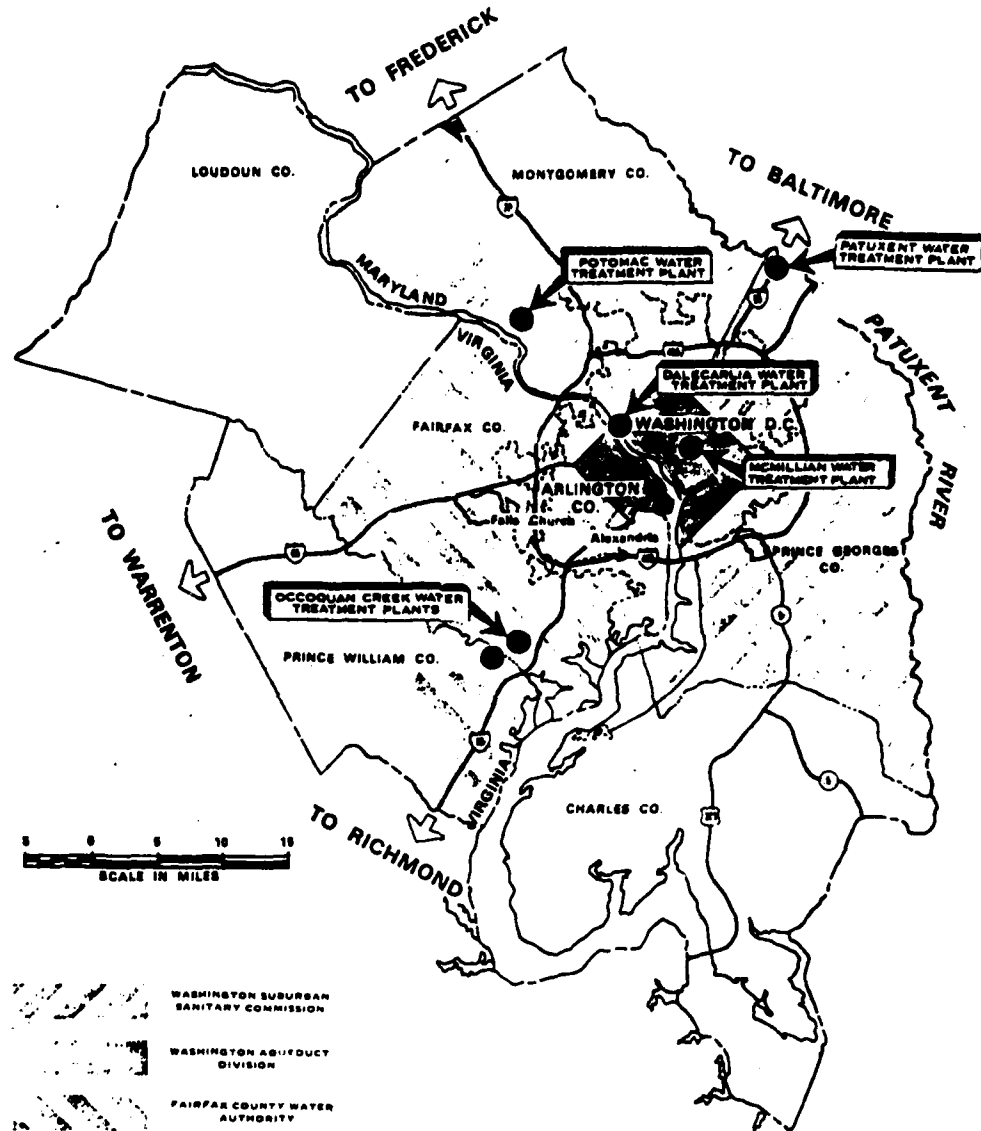


Figure 2

The WSSC, a public agency established by the Maryland General Assembly, is the major water supply agency for Montgomery and Prince Georges Counties. The principal sources of water for this system are the Potomac and Patuxent Rivers.

The FCWA provides water to both retail and wholesale customers in most of Fairfax County and the City of Alexandria as well as part of Prince William County in Virginia. The FCWA utilizes an impoundment on Occoquan Creek, as its raw water source.

Both the WSSC and the FCWA have applied to the Corps of Engineers for permission to build new water supply intakes on the Potomac River. WSSC wants to build a weir and new 400 mgd intake and FCWA wants to build a 200 mgd intake. As a result, the Potomac would then be called upon to furnish more water (an additional 400 mgd over present usage). As shown in Figure 3, the WAD intakes are the furthest downstream. WAD customers are concerned about the demands being placed on the river by the expanding suburbs of Maryland and Virginia. This issue is of great concern in regard to the issuance of the above permits.

With the above understanding of the MWA water supply situation, an examination of some of the water supply problems in terms of the legal, social, and economic parameters involving existing and future planning situations will be presented.

As one might suspect, the MWA water supply problems have been studied for many years with volumes of reports lining the bookshelves. However,

Potomac River Water Supply Projects in the Metropolitan Washington Area

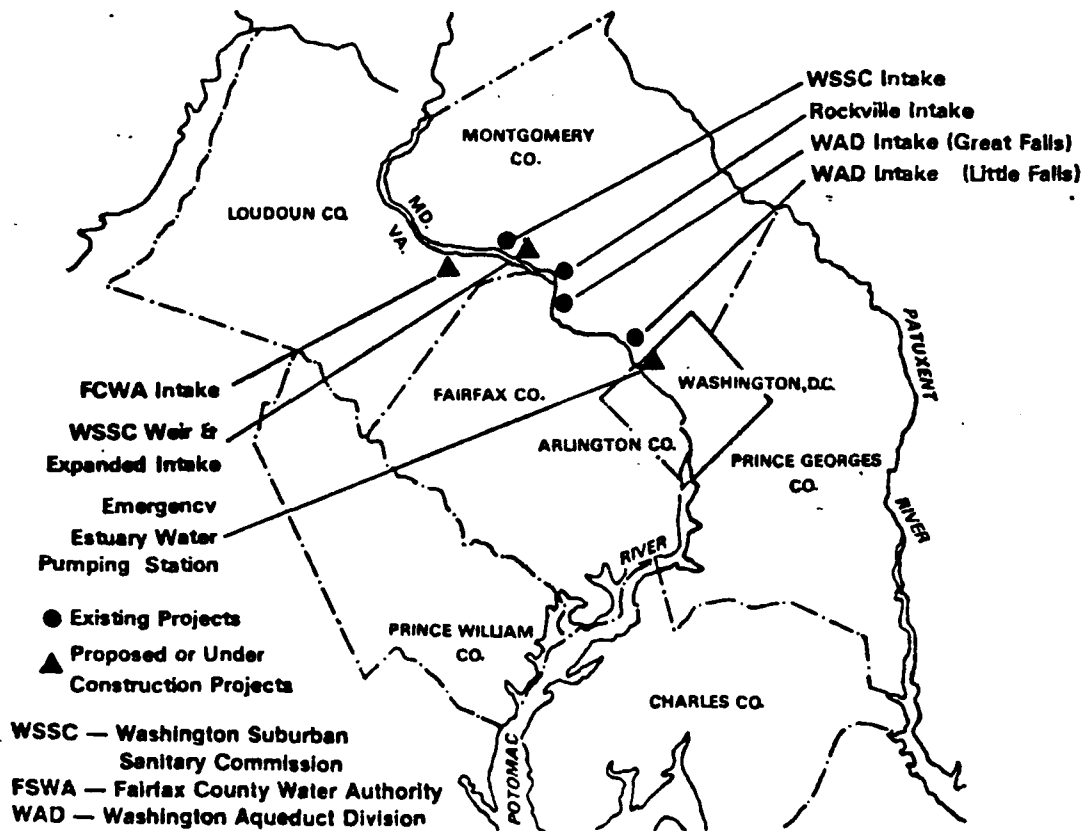


Figure 3

the MWA situation is now being analyzed from the viewpoint of "making the best use of its existing resources before constructing additional supply projects."

Many people believe that potential shortages can all but be eliminated to the turn of the century through more effective use of drought management techniques coupled with management of existing supplies. After the year 2000, additional water supply projects will be needed to satisfy normal demands.

What are some of the drought management programs currently being used?

The MWA recently moved into the legal arena concerning potential droughts by signing a "Potomac Low Flow Allocation Agreement (LFAA)." This agreement specifies how the Potomac River will be shared among all users during periods of critical low flows.

Obviously, this agreement did not come easily or over night. Many issues had to be resolved. An equitable formula for sharing this limited resource had to be derived. Equity among all users had to be assured -- both now and in the future especially to eliminate the prospect of decreased supplies for WAD customers as Maryland and Virginia suburbs grow. District of Columbia participation in projects developed by others needed to be assured as the District does not have the physical resources (land and water) to develop additional supplies. The LFAA was signed in January 1978 by the U.S. Government, the District of Columbia, the State of Maryland, WSSC, the Commonwealth of Virginia, and FCWA.

Key areas of the LFAA are:

- a. Allocation of Potomac River begins when water supply withdrawals equals or exceeds 80 percent of river flow.
- b. Recognize the need for environmental flow-by to the estuary.
- c. Allocation formula takes into account other sources of supply -- Patuxent and Occoquan systems.
- d. Any supply augmentation, reservoir, or treatment plan capacity developed after January 1978 is not subject to the allocation formula.
- e. The District of Columbia has the opportunity to participate in any additional supply augmentation project developed by other jurisdictions.

Coupled with the LFAA, the local governments through the Metropolitan Washington Council of Governments (MWCOG) have adopted a "Water Conservation and Coordination Agreement" (WCCA). This agreement is to provide interjurisdictional assistance and cooperation in the development of policies and plans for the conservation and management of water supplies in the MWA. The WCCA seeks to obtain: (1) regional adoption of plumbing code amendments to require water saving devices; (2) regional cooperation in the development of a public education program; (3) analysis of the use of water pricing as a tool for reducing water consumption; (4) adoption of a "Water Shortage Emergency Plan" (WSEM) to limit or curtail certain water uses during Potomac low flows; and (5) enactment of regulatory powers by all local governments to enforce successful implementation of the WSEM.

Because of the fragmentation of governments in the MWA and the realization that a regional solution was not to be forthcoming for quite some time and the experiences of water curtailment this past summer, both WSSC and FCWA have initiated local water supply studies.

A major component of the WSSC study deals with drought management or "What is the real cost of drought risks in terms of frequency of occurrence measured against dollars to alleviate that risk?"

As a result, WSSC developed drought management scenarios to analyze the trade-offs between constructing additional supply projects and the use of water use restrictions. The cost and inconvenience of the drought management measures, and the frequency they are implemented, need to be balanced with the cost of investing in additional raw water shortage.

As I mentioned earlier, drought management techniques must be coupled with some form of existing supply management. At present, either raw or finished water interconnections or both appear to be the best mechanisms to implement the necessary management concept. Simply put this concept consists of constructing interconnections between the three major water suppliers. During high and normal flows in the Potomac all three jurisdictions would withdraw raw Potomac water for water supply, as well as maintained existing reservoirs as full as possible at all times through natural fill or an interconnection to the Potomac. If the flow falls to critical or near critical stages, Maryland and Virginia would partially or totally discontinue pumping from the Potomac and would use the raw

water stored in their reservoirs. The water in the Potomac would be left for D.C. use. If river flow fell below the D.C. demand level, water from Maryland and Virginia could be provided through finished water interconnections or raw water interconnections back to the Potomac for release to D.C. While interest in this concept is strong, reservoir release schedules would have to be changed, water sharing through interconnections would have to be agreed to and monitored as well as water quality controls and conditions measured. Even with these potential problems, drought management and existing supply management appears to be the way for the MWA for the near future.

Obviously, each local government acting alone will not solve the problem (nothing described above adds any new water to the system) nor provide the most economical solution should they proceed beyond this concept. However, it appears any fragmented solution will help the long-term picture.

Several long-term solutions appear to have some support and are being investigated by the Corps in its present study. Local impoundments (i.e., those constructed within the MWA) and use of the Potomac Estuary.

Previous studies have all proposed upstream or headwater reservoirs for storing large quantities of water for release during low flow periods. However, upstream inhabitants are not willing to give up their lands for major reservoirs to mainly benefit downstream interest. Perhaps if large enough incentives were paid to those losing their lands, conditions would change, but the MWA has not reached this state as yet. And the

major suppliers (WSSC and FCWA) are turning to lands within their own jurisdiction for smaller impoundment sites and/or raising existing reservoirs. These are also meeting opposition. Because of the public outcry against dams and other major structural water supply solutions, Congress directed the Corps of construct, operate, and test a pilot estuary water treatment plant on the Potomac Estuary to determine the feasibility of using this water for a potable water supply source. The plant is now under construction and will use the latest state-of-the-art techniques (micro-screening, sedimentation, flocculation-coagulation, filtration, carbon absorption, reverse osmosis, ion exchange, electrodialysis, disinfection, ultraviolet irradiation, ozonation, etc.) in a two-year testing program to determine the economic and health feasibility of using the estuary as a water supply source. The Corps report is scheduled for completion in 1982.

This paper has outlined the water supply situation in and around the Nation's Capital by pointing out how local governments currently view solutions to a regional problem without taking a regional approach in solving that problem. The MWA can reorient its way of thinking and join together and cooperate in a regional drought management and existing supply management program. Obviously, the first step has been taken with the signing of the LFAA. Next comes sharing of existing supplies until this no longer meets normal average winter demands around the turn of the century. By then, agreements will have to be reached among all concerned for structural solutions which will add more water to the system.

Will people be willing to drink estuary water at a higher treatment cost to perserve upland lands from being inundated? Only time will tell!

WATER SUPPLY PLANNING IN ARID REGIONS
- EXPERIENCE IN THE MIDDLE RIO GRANDE BASIN¹

by

William K. Johnson

"After a while, one has to start living somewhere besides inside one's head."

- Theodore Roszak

This paper describes a water supply study in the Middle Rio Grande Basin being conducted by The Hydrologic Engineering Center, US Army Corps of Engineers, for the Albuquerque District, US Army Corps of Engineers, as part of the Albuquerque Greater Urban Area Study (AGUA). The AGUA study was authorized by Congressional resolution in 1974 and includes consideration of the needs for protection against floods, regional water supply and waste management, general recreation, enhancement and control of water quality, and enhancement and conservation of fish and wildlife. This paper deals only with one part of the investigation into water supply needs. Other aspects dealing with economic, institutional and legal problems are being studied by the University of New Mexico under contract with the Albuquerque District.

The Setting

Table 1 shows some of the geographic and demographic characteristics of the study area which begins at Cochiti Dam on the north and ends at Bernardo in the south.

¹ Presented at a training course on "Economic, Social and Institutional Aspects of Water Supply Planning", sponsored by the Institute for Water Resources, US Army Corps of Engineers, 20-23 March 1978, in Albuquerque, New Mexico

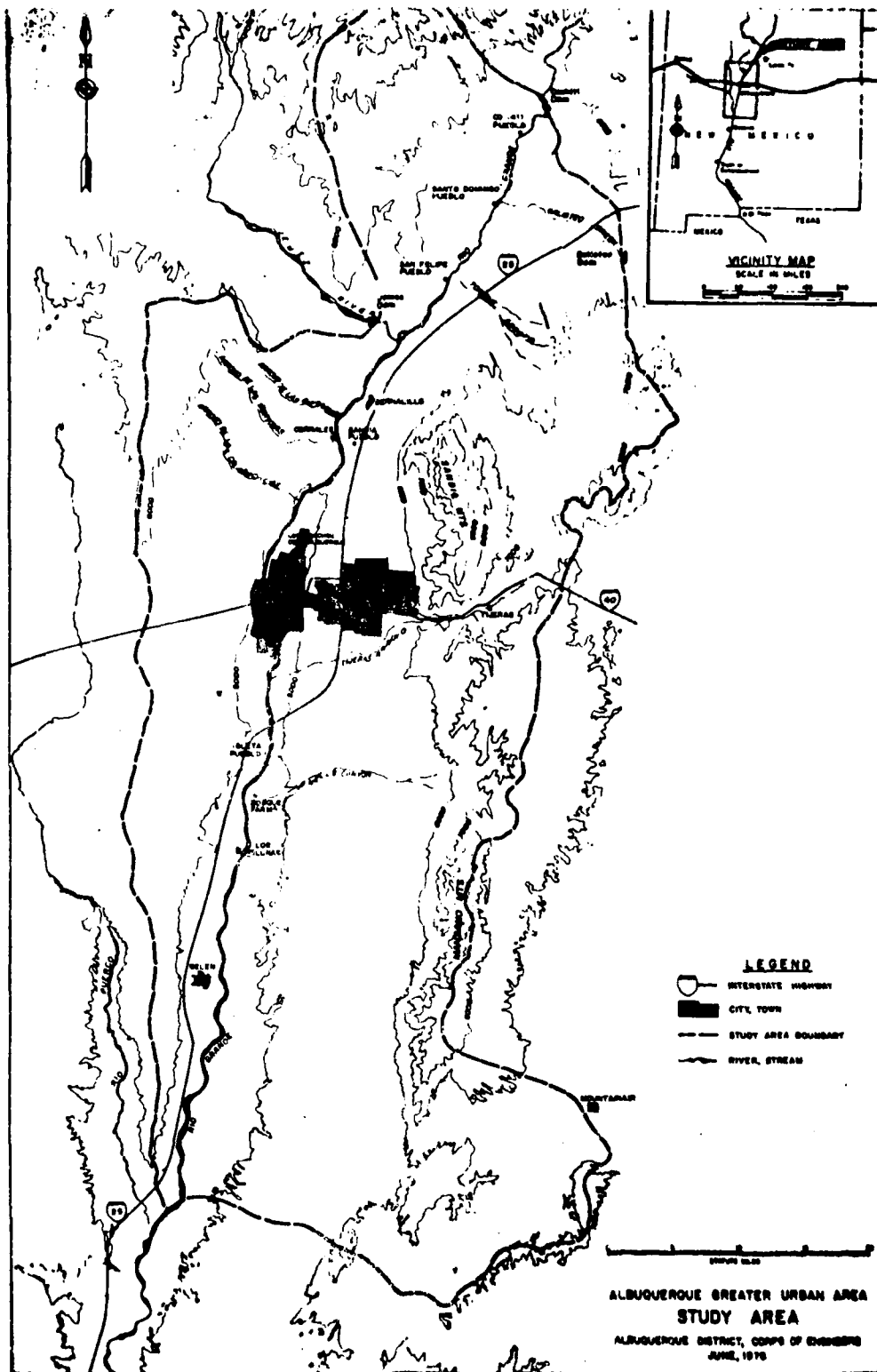


TABLE 1
MIDDLE RIO GRANDE STUDY AREA

Land Area	2700 square miles
City of Albuquerque	88 square miles
Topography	4,800 to 10,678 feet
Climate (annual rainfall)	8 to 30 inches
Population	412,800 persons
City of Albuquerque	290,000
North of City	40,300
South of City	82,500
Length of Rio Grande in Study Area	100 miles

Table 2 presents information which describes the water resource.

TABLE 2
MIDDLE RIO GRANDE WATER RESOURCE

Flow in Rio Grande River (last 10 years)	251,000 to 1,465,233 ac-ft
Well Yield (83 large discharge wells)	240 to 2000 gpm
Groundwater reservoir	Unconfined, 4000 ft thick
Water Law	Appropriation doctrine All waters fully appropriated
Water Use	
Agriculture (MRGCD Diversion, 1977)	411,170 acre-feet
Municipal and Industrial	113,528

An Assessment of Need

At the outset of this water supply study the principal problem was to identify the needs which the study should address. During the previous four years four comprehensive federal studies had been completed. These studies are identified in Table 3. Various special studies were also conducted by local and State water planning agencies. In addition an Advisory Committee of local, State and Federal water officials had made recommendations of planning objectives for water supply. While these recommendations had identified important study areas the level of funding required was much greater than that available. Lastly, State and local water managers were consulted on an individual basis for their advice in scoping the study.

A number of options surfaced: development of a groundwater model; assessment of future supply and demand; establishment of a data storage-retrieval system; investigation of alternative strategies for managing the resource. None of these, however, seemed to fit what local and State water managers needed at this point in time and what would be worthwhile as a foundation to build upon for the future. The needs ultimately identified for investigation included,

- . A quantitative description of the hydrologic, hydraulic, and water quality characteristics of the ground water/surface water resource.
- . A water budget of past and present water supply and use.
- . The impact of drought conditions on water supply.
- . Identification of present water management decision-making practices.
- . Potential use of digital computer programs.
- . Impact of potential management strategies on the ground water/surface water resource.

Collectively and individually these topics were intended to investigate the water resource itself - the physical substance we call water and its

TABLE 3

SUMMARY OF FEDERAL STUDIES 1974 - 1976

<u>Study</u>	<u>Study Area</u>	<u>Conclusions</u>
Upper Rio Grande Basin water and Related Land Resources U.S. Department of Agriculture Economic Research Service, Forest Service, Soil Conserva- tion Service, October 1974.	Colorado State Line to Elephant Butte Dam (29,696 square miles)	<ul style="list-style-type: none"> Land treatment to increase water yield Improve irrigation and delivery efficiencies, increasing yield from watershed, decreasing nonbeneficial water use.
Westwide Study Report on Critical Water Problems Facing the Eleven Western States U.S. Department of the Interior, Bureau of Reclamation, April, 1975	State of New Mexico (121,666 square miles)	<ul style="list-style-type: none"> Transferring water rights from one use to another. Ground-water resources could be further developed.
Summary Appraisals of the Nation's Ground-Water Resources: Rio Grande Region U.S. Department of the Interior Geological Survey, 1975	Colorado State Line to above Elephant Butte Dam	<ul style="list-style-type: none"> Draw upon water stored in underground reservoirs Water could be salvaged by eliminating wetland and phreatophyte areas
New Mexico Water Resources Assessment for Planning Purposes U.S. Department of the Interior Bureau of Reclamation, Nov. 1976	State of New Mexico (121,666 square miles)	<ul style="list-style-type: none"> Better watershed management Planning information Transfer of water rights

management. This is in contrast to legal, social, economic, or institutional aspects of water. Many of these topics were investigated in other parts of the AGUA study.

Understanding the Resource

An underlying premise which developed early in the study was that wise water management decisions must be founded upon a good understanding of the resource which is being managed. Without a clear understanding of the water resource, its availability, and its response to man's activities it is difficult, if not impossible, to effectively manage that resource. The first item selected for investigation was to update current knowledge of the hydrologic, hydraulic and quality characteristics of the surface and ground water. It was fortunate that the U.S. Geological Survey had conducted investigations of this type in 1960 and 1967. The results of these studies were being used by both the State and local water agencies. Since 1960 additional data had become available and it was important that these data be used to update the earlier investigations. The update included such information as: mapping of the coefficient of transmissibility, mapping of changes in water table over time, estimates of drawdown for the year 2000, reevaluation of the coefficient of storage, and a general assessment of the response of the ground-water aquifer to pumping stress. This work was done under contract by a consultant with experience in geohydrology in the study area.

The second item investigated was the water budget. An attempt was made to quantify the supply and use of the resource such that all water in the study area was accounted for on an annual basis. This work required the identification of all major components of use and supply, their quantification and interrelationship one to another. Components considered included: precipitation, ground water, surface water, ground water recharge, evapotranspiration, imported water, consumptive use, waste discharge. By attempting to quantify these items on an annual basis and over the study area the quality, availability and usefulness of different

information became evident and appropriate recommendations for data collection and management could be made. This work was done under contract with a local engineering firm which had access to much of the data needed.

The assessment of the impact of drought conditions was directed toward identifying the type and magnitude of stress which could be placed upon the water supply sources. This included consideration of historic low flows in the upper and middle Rio Grande Basins which would directly affect the Rio Grande River - the principal source of surface water in the study area. This assessment will be both qualitative and quantitative and should be useful in understanding how a shortage of supply over a number of years could affect water availability.

To better understand how improved analytical techniques might play a role in water management those methods and techniques currently in use were identified and described. Of special interest was the State Engineer's methods for estimating the time which occurs between beginning pumping of a well and its affect on the Rio Grande. The methods used were known generally, but their detail had not been made explicit and evaluated in light of actual water table drawdown and well field layout. This activity was to set the stage for a consideration of computer models to assist decision making.

The investigation into the potential application of digital computer programs to the middle Rio Grande Basin focused on two uses. The first was to model the ground water and/or surface water system. The questions to which answers were sought included: what utility would a model be? what management information could be provided? how much would a model cost? how long would it take to collect the necessary data? The second use of digital computation investigated was for storage and retrieval of water data. A data management system might be of use in managing various types of data used to make management decisions.

The last topic investigated was the impact of potential management strategies on the ground water/surface water resource. With the information provided by the investigation of the other topics - updated physical

characteristics, a water budget, the stress induced by a drought, potential of analytical techniques to improve data management and analysis - with this information available the probable impact of various management strategies could be assessed. These strategies included: means to reduce uncertainty in present knowledge of the resource, means to reduce the water budget deficit, and means to more effectively manage the resource.

Conclusions

The experience of this study and the experience with a broader range of planning investigations has shown that developing timely, responsive, and useful information as part of a federal planning study is not an easy task. There is a great tendency to 'follow in the train' and do traditional river basin planning. Many are quick to suggest that a 'model' is needed. Others see economic, social, institutional and legal studies as a fruitful endeavor. These are all interesting subjects and it is easy for them to capture our attention. Yet, outside our heads the human need is often much more basic. It is having water to drink and to use which is: of an acceptable quality, at a convenient location, at a reasonable cost, and available when we need it. Providing information to help meet these needs is sometimes the most worthwhile planning we can do.

Chloride control of water supply in a semiarid area and a plan for Chicago to reduce storm water damage and improve water quality.

Water Supply and Water Quality Planning Conference
December 10, 1975
Atlanta, GA.

CARL H. GUAM
Chief Central Reports Management Branch
Planning Division, Civil Works
Office of the Chief of Engineers
U. S. Army Corps of Engineers

NOTE:

The two projects are still under study and therefore will be discussed conceptually. Plans and benefits may change prior to finalization of reports.

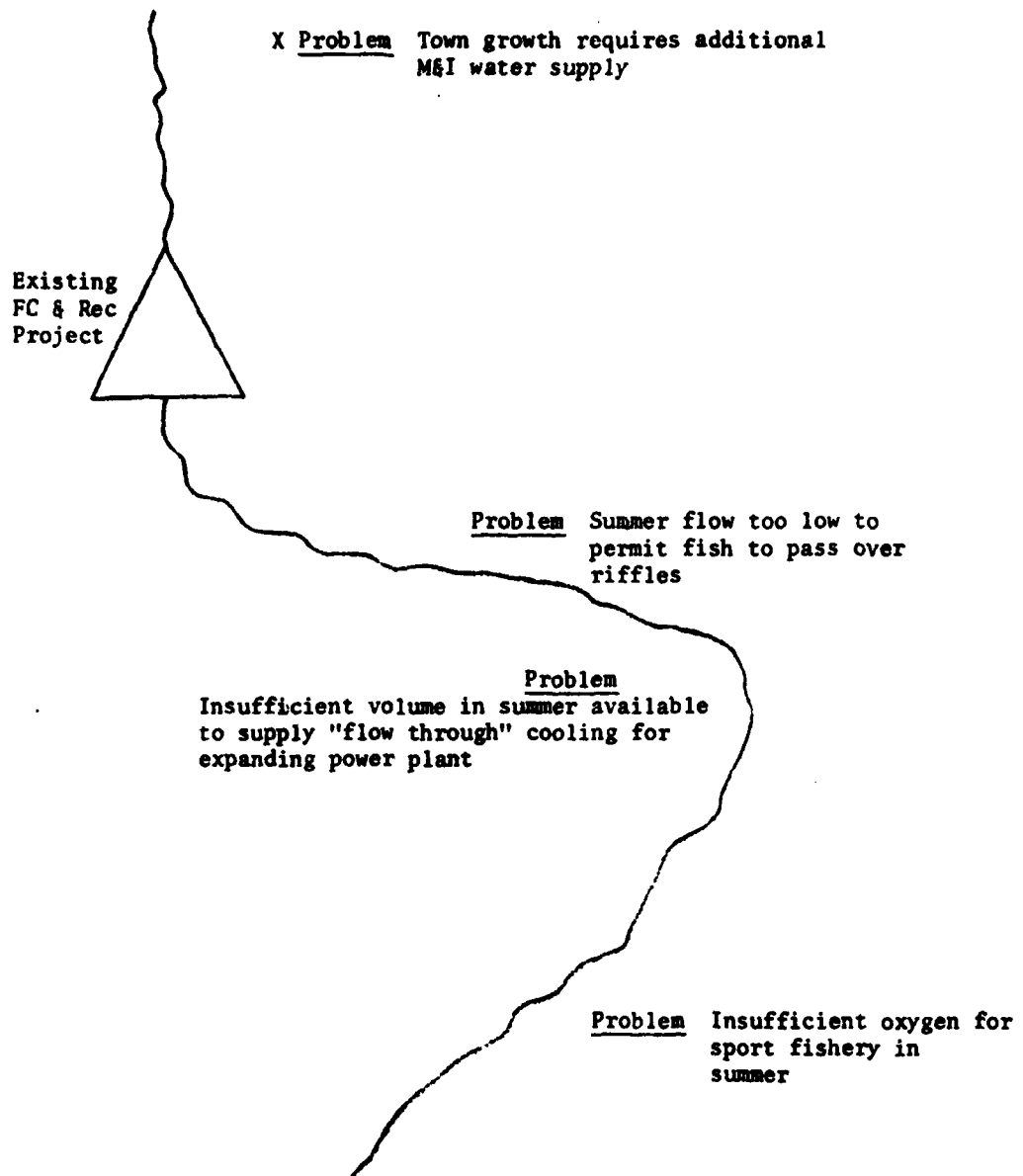


Figure 1

ARKANSAS-RED RIVER BASINS WATER QUALITY CONTROL PROJECT

The area is in need of additional good quality water since average annual rainfall is as low as 18 inches per year.

Preliminary investigations by the Public Health Service several years ago revealed that 15 significant sources of natural chloride pollution in Texas, Oklahoma, and Kansas, are the primary cause of water degradation. In addition, man-made brines enter the basins' waters, largely from petroleum and natural gas production. Chlorides pollute the waters of over 1,000 miles of streams in each of the major basins, making them unusable for most principal, industrial, and agricultural purposes. On an average, 20,000 tons of salt are carried each day by the Arkansas River past Van Buren, Arkansas, and 7,000 tons daily by the Red River past Index, Arkansas. Approximately 15,000 tons of the salt come daily from 15 natural sources, while the remaining 12,000 tons are from man-made pollution and other minor natural source areas. (See Figure 1) To date, the main emphasis of water quality improvement and maintenance programs has been toward controlling man-made pollution. Waters for considerable distances on these streams are limited in use because of the far-reaching effects of natural brine emission. The improvement and preservation of the water quality in these basins is essential for full utilization of the surface water supply. There is an immediate need for additional good quality water in and to the west of the areas of natural salt pollution and a large potential need downstream from these areas in the eastern portion of the basins.

The plan of improvement that was recommended by the Chief of Engineers is part of a Federal-non-Federal program to clean up and conserve water in each basin for fish and wildlife enhancement, recreation and agricultural, industrial, public water supply and other uses by reducing both natural and man-made chloride sources which make the waters unfit for most human uses and deleterious to fish and wildlife. Implementation of the overall plan, although it does not guarantee the availability of water from either basin at the time or place of need, will make these waters acceptable for potential human use and ready for the non-Federal investment in storage and conveyance facilities that may be necessary to assure a continuous supply for municipal, industrial, agricultural, and other possible uses.

The Chief of Engineers initially recommended the construction of three brine control dams with conveyance systems to two separate brine storage reservoirs in the Wichita River Basin upstream from Lake Kemp in Texas. These improvements were authorized in the Flood Control Act of 1966 subject to proviso that construction not be initiated until the related and supporting works of Part II have been authorized by Congress. On May 6, 1970 the Chief of Engineers submitted his

recommendations concerning construction and operation of the Red River chloride control project, which would supplement the Wichita River portion of the overall plan, and the Arkansas River Chloride Control project in the Part II report to the Secretary of the Army. These much needed improvements were authorized for construction, in the Flood Control Act of 1970, together with the previously authorized Part I improvements on the Wichita River, subject to approval of the Secretary of the Army and the President. The 1974 Water Resources Development Act authorized construction for the area VIII.

The project is currently in the advance engineering and design stage. The map shows the location of the elements of the plan.

Primarily the plan provides for inflatable dams on the major tributaries to capture the seepage during low flows conditions. The impounded saline waters would then be pumped to evaporation ponds. During higher run off when salinity is low the dams would be deflated and the stream flow allowed to pass downstream. It will take many years probably 20 or so before the stream beds are flushed of accumulated salts. In the Estelline Spring, area V salt water seeps where surrounded by ring levees in 1964. This seems to be working as a practical way to limit brackish water discharges. The impounded springs have been confined and salt water has not appeared at other possible out flow points.

Another technique tested in the Jonah Creek element of Area XII is to capture the under flow by placing a series of drains in the stream bed. The collected seepage is treated to prevent bacterial or fungus growth and prevent blockage of screens in the deep wells into which the water is injected. Although this scheme is working well, the uncertainty of finding adequate formations for larger amounts of disposal water has resulted in this method not being farther pursued. The existing test program will however, continue although at this time the plan for surface disposal will be implemented.

1974 estimated costs for implementation of the total plan was \$525 million. Six hundred thousand dollars of this would be non-Federal for recreation development. Recreation is not a project purpose. The cost estimates will be revised as the plan is refined. Costs and benefits do not include the elimination of man-made pollution which it assumed will be corrected by industry and others responsible.

Benefits:

One of the key problems with the study was determining the benefits as a result of removing the salts from the water supplies. A consultant's report developed a means of assessing benefits for various reductions in salinity.

The benefits are based on greater agriculture production or reduction in treatment costs for industry or municipal supplies in relationship to various reductions in chlorides. For various crops and industrial processes curves were generated to plot crop production or treatment costs vs various salinities. (See Figures 2, 3 & 4). There were then related to frequency of occurrences of various salinities with and without the project and seasonally adjusted. From these curves average annual benefits for various stream reaches could be determined and average annual benefits computed. Average annual benefits would then be related to the project feature which generates the salinity reduction.

Since the study has not been completed total benefits are not available. Nevertheless indications are the project will have favorable benefit cost. The technique is particularly useful as it allows benefits to be related to various reaches of the waterways. The downstream areas receive the best water and it is estimated the plan will be able to provide good water in Lake Texoma where currently the water is of poor quality 78 percent of the time.

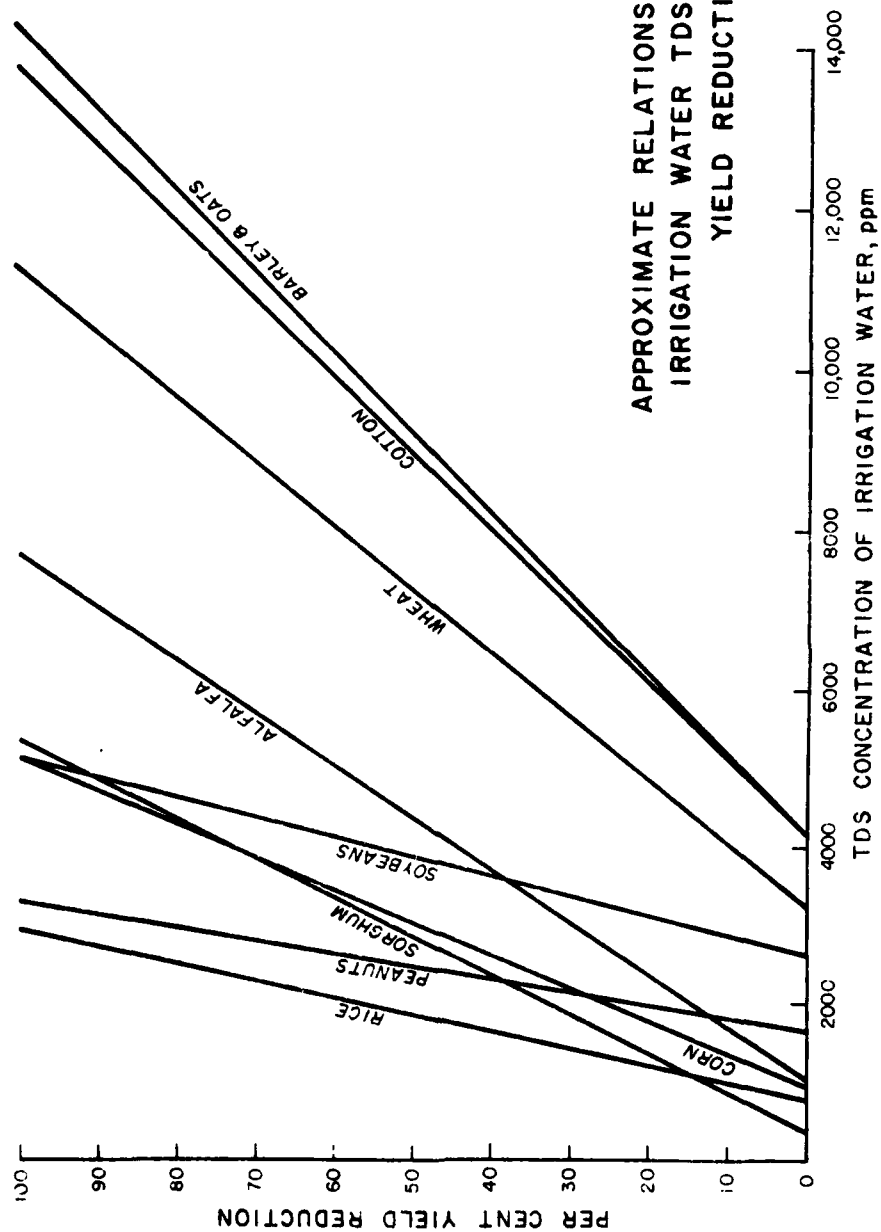
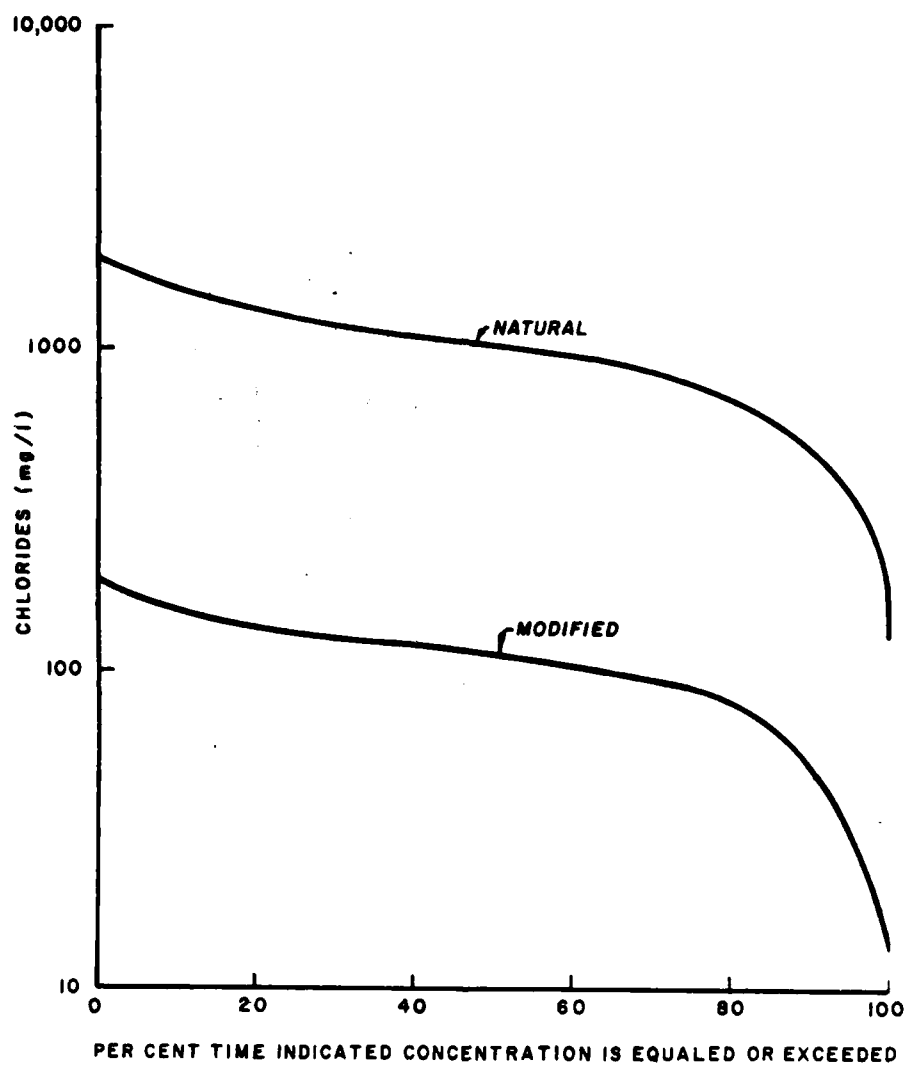


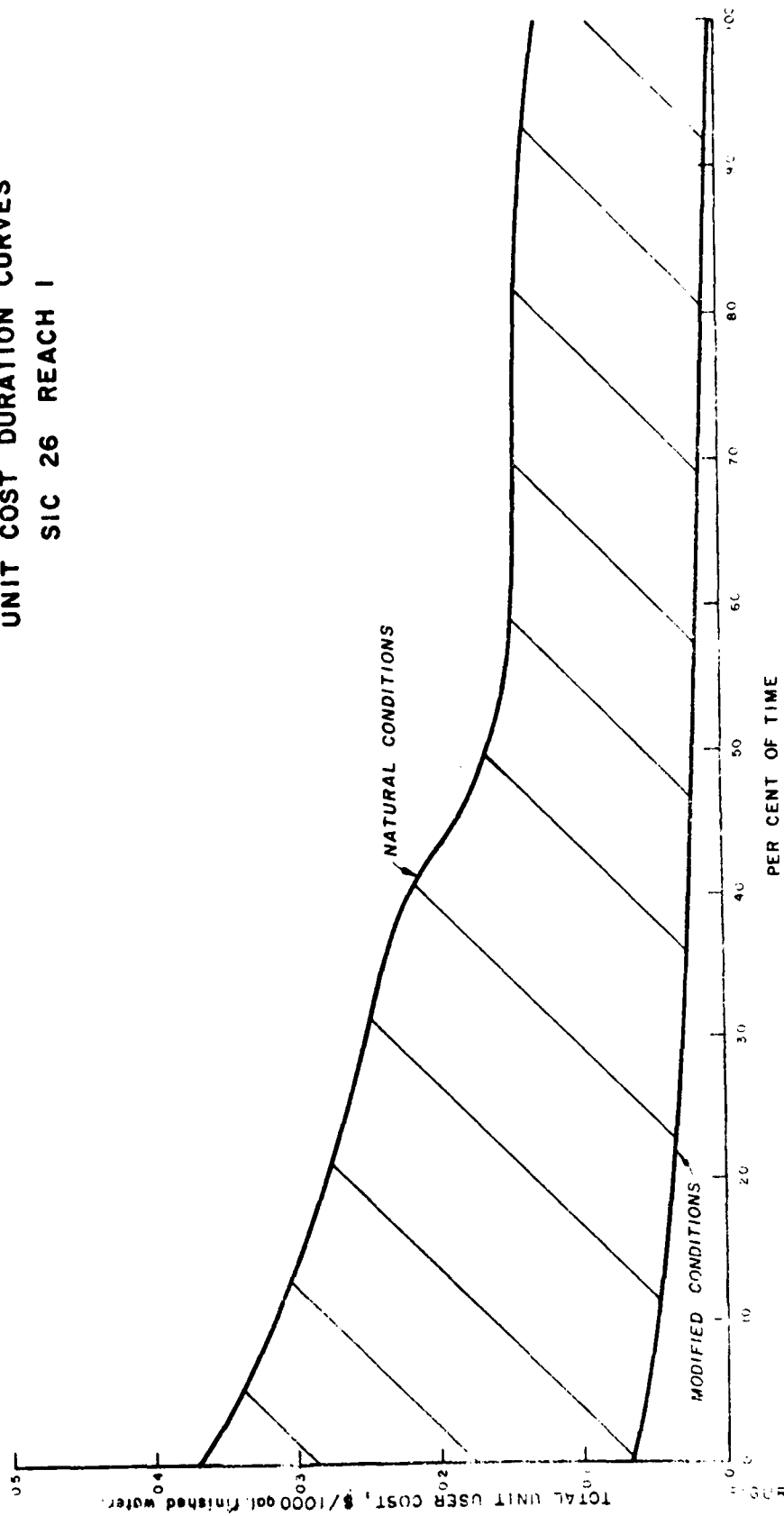
FIGURE 2



CHLORIDE CONCENTRATION
DURATION CURVE
REACH 6
NATURAL AND MODIFIED CONDITIONS

FIGURE 1

UNIT COST DURATION CURVES SIC 26 REACH I



CHICAGO UNDERFLOW PLAN

SYNOPSIS

The "Chicago Underflow Plan" is a scheme to provide flood and water pollution control to a portion of the Metropolitan area of Greater Chicago. The problem is one of inadequate drainageways to carry the runoff from combined sewage and storm water drains in an expanding urban area. This results in increased and highly polluted runoff flooding local improvements (mostly basements). The runoff also pollutes Lake Michigan and adjacent waterways. The cheapest tentative alternative solution to solve both problems is to upgrade the present combined sewer collection system and to construct collector tunnels up to 42 feet in diameter, some 50 to 300 feet below grade. These will empty into a below grade reservoir to await processing to meet water quality standards.

The plan was conceived and studied by the Metropolitan Sanitary District of Greater Chicago (MSDGC). This report deals with the Federal interest and involvement.

THE AREA

The study area is comprised of the Greater Chicago Metropolitan Area including the City of Chicago and 43 nearby communities with an area of 375 square miles entirely within Cook County, Illinois. The system would collect combined sanitary and storm runoff from about 39% of Cook County. The combined sewer service area has a present population of about 4 million persons and an ultimate population of about 4.7 million persons.

The topography is comparatively flat with poor definition between drainage basins. The high degree of development and construction of relatively impervious surfaces results in a high degree of runoff and attendant flooding problems. The soil is of glacial origin and is relatively thin, less than 100 feet in most areas being considered for tunnels. Underlying this is a layer of dolomitic limestone which is up to 300 feet thick. Below this is 200 feet of shale.

Historically the eastern and southern portion of the area drained into Lake Michigan, with the remainder of the area draining through the Des Plaines River into the Illinois River. Initially, the sanitary sewers of Chicago also drained into Lake Michigan. Several canals constructed between 1871 and 1922 reversed the flow from the eastern and southern portions so that runoff flowed into the Illinois River Waterway rather than Lake Michigan, except during period of great storms. This resulted in a much lower pollution potential in Lake Michigan, the main source of potable water for the City of Chicago. Water from Lake Michigan is used in non-storm periods to dilute and help convey polluted waters to the Illinois River Waterway. Supreme Court decisions in 1930 and later, restricted the amount of water available for withdrawal from Lake Michigan including diversion to the Illinois Waterway, to 3,200 C.F.S.

THE PROBLEM

Initially the sanitary flow and the storm water drainage were conveyed through the same pipelines (sewers) to the nearest stream and released. Eventually sewage treatment works were constructed and later interceptors were constructed to keep sanitary waste flows out of the streams. Flows greater than design would be diverted to the nearest stream (see Figure C-1). Thus the streams were still receiving polluted flows, primarily during periods of high precipitation. Initially the sewers were designed for a five-year frequency rainfall plus the normal sanitary flow. Increases in sanitary flow over the years have reduced the available capacity for storm flows. The low initial design criteria plus increased rates of floodflow due to urbanization have resulted in a flooding problem. This is primarily in the form of flooded basements and flooding at railroad and highway underpasses. Overbank flooding adjacent to existing streams is present but damage is of a much lower magnitude due in part to the presence of parks along much of the Des Plaines and Chicago Rivers and the ability to divert excess flows into Lake Michigan.

The Illinois Pollution Control Board now requires that "All combined sewer overflows and treatment plant bypasses shall be given sufficient treatment to prevent pollution or not violate any of the applicable water quality standards". The Board has given communities until December 31, 1977 to meet these standards. This is part of the compliance necessary to meet the standards of the Federal Water Pollution Control Act Amendments of 1972.

The pollution control standards will require the elimination of any polluted overflows to Lake Michigan. This will mean higher stages in the streams affected and more flooding along the streams. It will also result in backup of the combined sewers and more frequent flooding of streets and basements.

INVESTIGATION

Recognizing that the problems of flood control and water quality are interrelated in this area, the local Governments and Sanitary Districts joined together and formed a Flood Control Coordinating Committee in 1967. The committee could not come to a final recommendation and was abandoned in 1968. It was reactivated in 1970, and made a detailed study of the problem.

Of the 23 alternatives and their variations studied it appeared that four were the least costly and were environmentally acceptable. These were studied in further detail by the coordinating committee. A composite of the alternatives was selected as the best plan. The recommended plan (see Figure C-2) consists of:

- a. 120 miles of deep underflow conveyance tunnels varying from 10' to 42' in diameter.
- b. 644 existing sewer overflow points will be connected to 341 drop shafts.

c. A primary storage reservoir 300 feet deep in bedrock with a storage volume of 57,000 acre feet. An aeration system will be constructed within the reservoir to eliminate septic conditions. A second reservoir is planned for the O'Hare area.

d. A dewatering pumping station to dewater the reservoir in not less than 50 days under extreme conditions and 2 to 10 days under normal conditions. The liquid will be transferred to appropriate facilities for treatment prior to discharge for the area streams.

e. An on line storage reservoir to dampen peak flows.

f. A pipeline from the reservoir to a treatment plant.

g. Fresh water aquifer protection in the form of grouting of tunnels in required areas, and recharge wells in certain areas.

h. Incorporation of some sanitary sewage flows within the system to avoid expenditures for enlarged interceptors.

i. Widening the sanitary and ship canal to handle greater flood flows. Polluted bottom deposits will be removed. Provision could be made for overflow of canal waters into reservoirs during periods of some high flows.

j. Upgrading of treatment plant facilities to meet future water quality standards.

The plan will not allow for total containment of flows from rare, very large storms. The flows occurring at the start of the storms have the highest pollution content and these initial flows will be carried to the reservoirs. Later flows in excess of the system capacity will be diverted to the natural waterways. The natural waterways capacity may be exceeded and flooding can result but would be rare.

In 1973 both the Senate and House Public Works Committee adopted resolutions for the Board of Engineers for Rivers and Harbors to investigate and determine the appropriate Federal Interest in the plan. A public hearing was held by the Senate Public Works Water Resources Subcommittee in Chicago on 28 March 1974. All testimony was in favor of the project.

In addition to the Flood Control Coordinating Committee plan, the Corps of Engineers Chicago District, in their study have added the requirement of improving the existing storm sewer system. Without these improvements the design potential for improved flood control will not be realized.

The Corps of Engineers is presently preparing a study entitled "Chicago - South End of Lake Michigan, Urban Water Damage Problems" (C-SELM). The study covers an area of 2600 square miles in 7 counties of Illinois and Indiana with a population of about 7 million. The Chicago underflow plan

area is that part of the CSELM area served by combined sewers. The Chicago underflow plan goals are found to be consistent with the C-SELM goals.

BENEFITS

The benefits derived from the plan are as follows:

<u>Water Damage Control</u>	<u>Average Annual Benefits (in millions)</u>	
1. Sewer Upgrading (a)	\$129.3	
2. Flooding, Basement	191.3	
3. Flooding, Overbank	13.5	
4. Recreation Enhancement (e)	3.5	
	<u>\$337.5</u>	<u>46%</u>
 <u>Water Quality Control</u>		
1. Compliance with standards (b)	\$337.3	
2. Water Supply (c)	3.3	
3. Inadequate Interceptor Capacity (d)	10.5	
4. Recreation Enhancement (e)	7.7	
	<u>\$398.8</u>	<u>54%</u>
 TOTAL	 \$736.2	

- (a) Benefits are considered equal to the costs of upgrading the sewer system.
- (b) Benefits are considered equal to the least costly alternative cost of compliance.
- (c) Additional water from Lake Michigan available for other use than pollution dilution.
- (d) Savings thru use of the tunnels in lieu of new interceptor sewers.
- (e) Based on increased usage.

Costs

The total estimated costs amount to \$4,598.5 million for construction and \$1,156.3 million for interest during construction for a total of \$5,734.8 million. This results in annual costs of \$410.6 million and an overall B/C ratio of 1.75.

Cost Allocation

The costs of joint facilities were distributed in proportion to some comparable measure of use, in this case the volume of overflow. Simulated routings of the July 1957 storm were used to establish the allocation

parameters. A total of 90,000 A.F. of run-off was available to the system, however, only 72,900 A.F. was considered effective. The first 24,000 A.F. was credited to Water Quality Control as the "first flush" contains most of the pollutants. The remaining 48,900 A.F. was credited to Flood Control, a 33%-65.35% split. Items not having ajoint use are wholly charged to the individual use. The key issue to resolve is the Federal-local cost sharing. Studies are still underway.

TYPICAL SEWER NETWORK

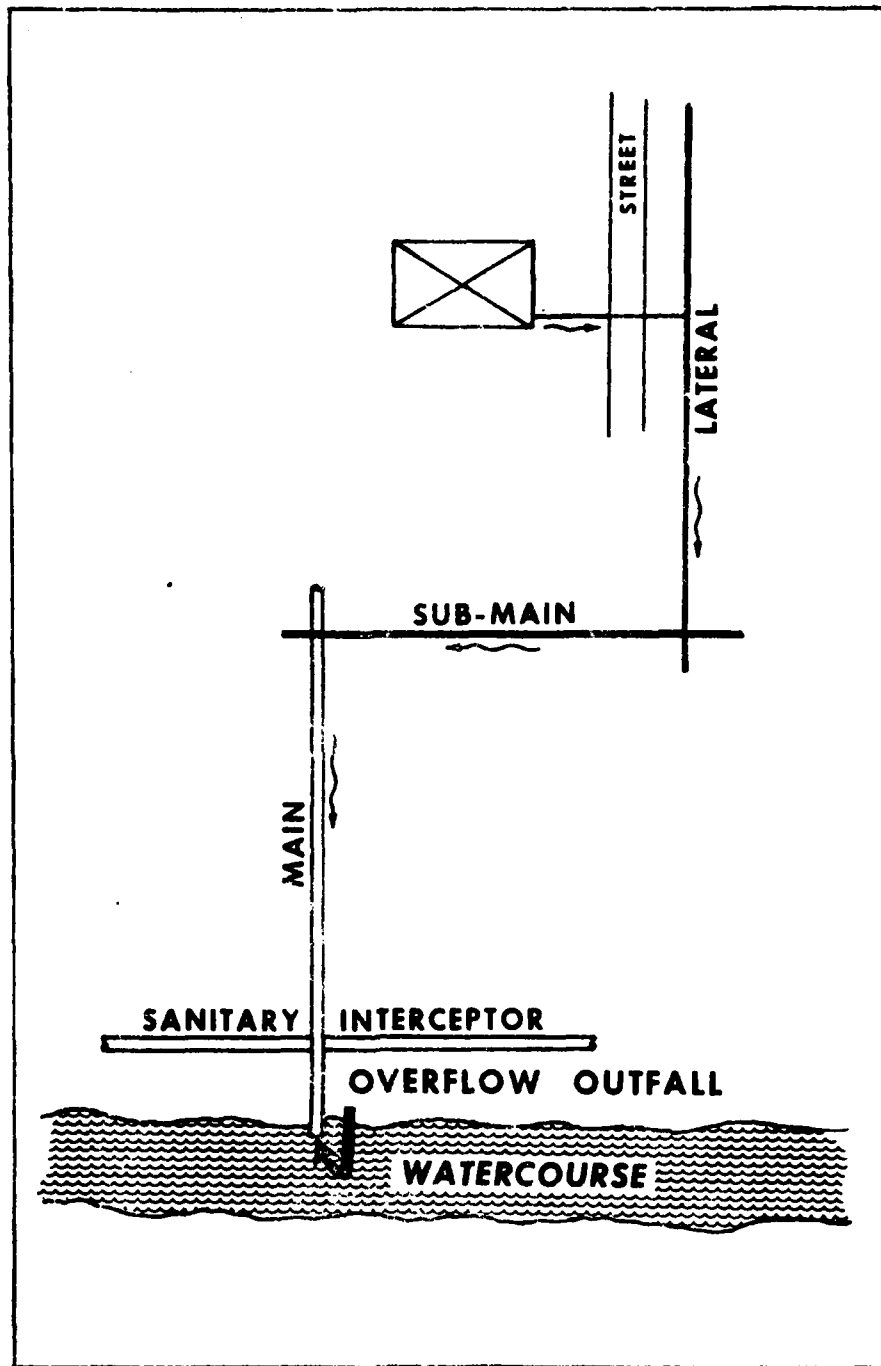


FIGURE C1

Table 5 Framework for Plan Implementation

System Feature	Responsible Non-Federal Agency 1/	Purpose-Control of		Function
		Water	Pollution	
Upgrade Sewer System	Community	X	-	Reduce extent & frequency of flooding.
Collector System	Community & MSDGC	X	X	Capture & convey runoff from community to tunnels via drop shafts.
Tunnels & Reservoirs including Conveyance System	MSDGC	X	X	Control of flood stages & pollutant levels in watercourses; convey storage for treatment & release at non-damaging rates.
Upgrade Plant Capacity and Treatment Level	MSDGC & State	-	X	Control quality of discharge to watercourses.
Sludge Management System	MSDGC & State	-	X	Dispose of sludge in a safe and environmentally sound manner.
Appurtenant Works	MSDGC & State	X	X	Maintain watercourse profile, consistent with design river stage and quality criteria

1/ Includes agencies responsible for actual implementation and/or final certification relative to Federal programs. Certification by the Northeastern Illinois Planning Commission as regional clearinghouse agency also required.

TUNNEL AND RESERVOIR PLAN (1975)

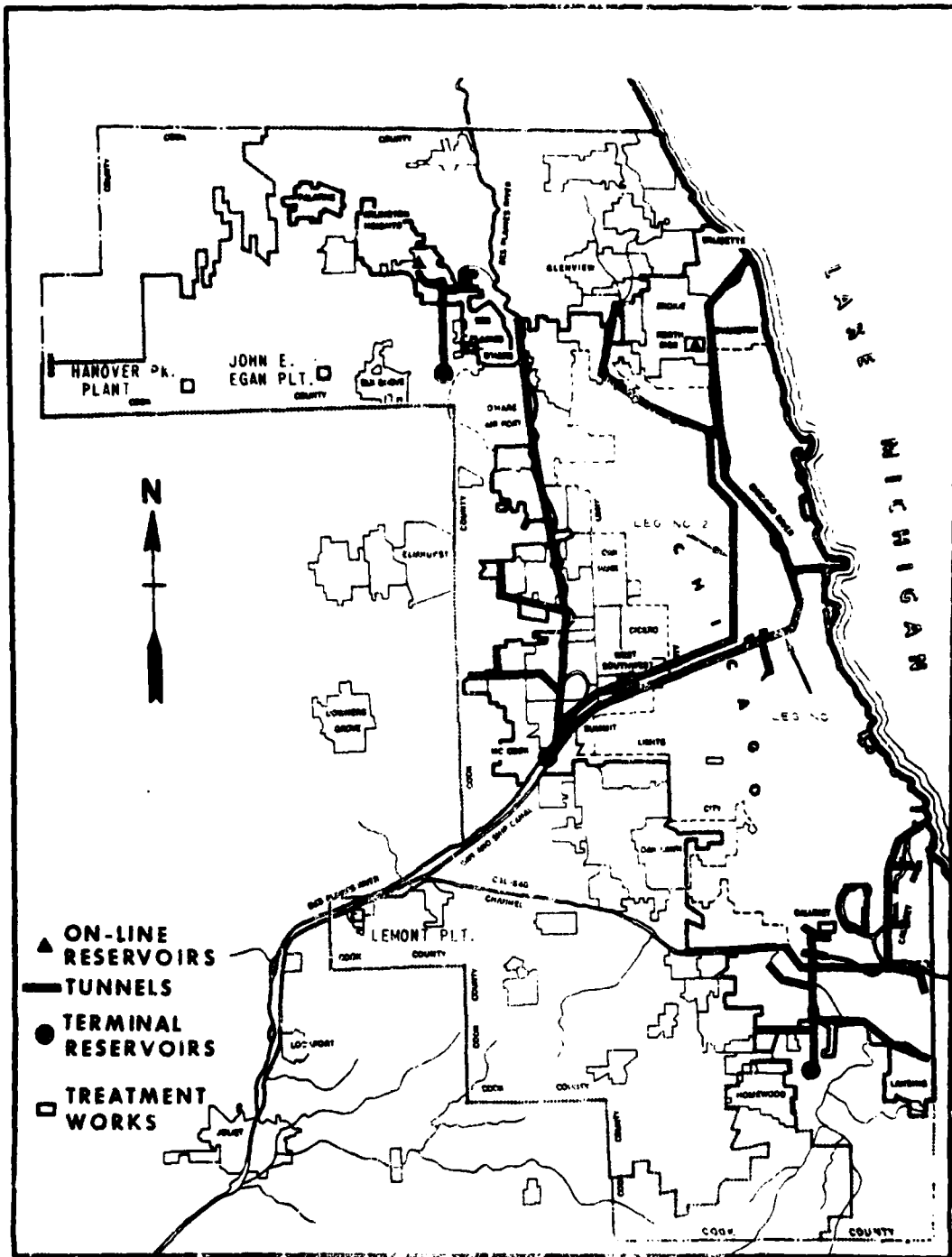


FIGURE C2

the communities to the MSDGC treatment plants. Added capacity is required to accommodate the daily variations of the projected dry weather flows. However, it was subsequently concluded that the proposed tunnels could be used to convey the excess in the peak dry weather flows to the treatment plants. With the tunnels carrying this flow, some \$208,000,000 in savings was realized in the combined sewered area. Upgrading of sanitary interceptors in the separately sewered area is still required.

Tunnel and Reservoir System

The tunnel and reservoir system is actually made-up of five different components. Included as construction features are a collector system, 125 miles of tunnels, a groundwater protection system, two on-line reservoirs and three terminal (retention) reservoirs. The recommended plan still includes four main tunnel conveyance systems; however, the configuration, size and area serviced have been modified. In addition, there have been modifications to the storage facilities. The alignment of the tunnels and the location of both the reservoirs and the treatment plants are shown in Figure 5.

Mainstream System

The excess overflow from about 60 percent of the study area is captured by the Mainstream tunnels and reservoirs. A collector system with drop shafts is used to intercept and divert the runoff from the overflow outlets to the tunnels. Basically, the system provides a free draining outlet for some 20 communities, portions or all of which are located in the affected service area. However, system design does permit spillage in the North Shore and Main Chicago areas, but only if the most severe storms of record were to recur. The rate and volume, though, are controlled so that the spillage does not become a source of damage or pollution. Sufficient in-line storage is provided to avoid spillage in the area tributary to the North Branch of the Chicago River upstream of the North Shore Channel. The in-stream capacity of the North Branch is limited by inflow from outside the study area.

Some 58 miles of main-line tunnels and extensions are required to convey the overflow to the terminal reservoir near the existing West-Southwest treatment plant. Plans call for the reservoir to be located in a commercial quarry about two miles south and west of the plant. The amount of storage at the terminal reservoir has been reduced from 118,000 to 82,000 acre-feet because of the separation of the Calumet system. In addition, an on-line underground reservoir adjacent to the existing North Side treatment plant has been provided. This reservoir controls only in-line back-up and permits the use of smaller sized tunnels in the North Shore and Main Chicago areas. The room and pillar construction method will be used to create this 2,900 acre-foot storage area in the rock strata underlying the plant.

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Costs and Effects of a Water Quality Program
for a Small Strip Mining Company

This report by Richard Drees of West Virginia University and Harold Bryant of Xavier University performs an economic analysis of the market demand and supply conditions of a small family-operated strip mine located in Southeastern Ohio. The mine represents a large share of operators in the coal industry which supply only a modest share of the market. In 1968, 73.3% of all mines produced less than 50,000 tons per year with a total market share of 10.2% while 5.1% of total mines produced more than 500,000 tons per year for a market share of 58.5%. Since the economic status of the small mine is insecure, an environmental control program can have serious impacts on the limited earnings typical of small operators. Analysis of the target mines demand and supply conditions indicated that water quality policy based upon performance criteria (p.H. and sediment) could be satisfied economically. Policy based upon imposition of required technology would likely prove to be an uneconomic burden.

Study Results

OBJECTIVE 1. Measure quantity and quality of acid mine drainage attributable to current stripping operation of the company (the without condition).

Runoff in pits has a p.H. of 3.0 or below, acidity of 900 mg/l and relatively high levels of sulfate, iron, aluminum and manganese. Overflow is free from sediment and water quality measurements are better than those of receiving streams.

Relatively poor water quality of receiving water is mainly attributable to effects of deserted and abandoned mines and natural acid runoff.

OBJECTIVE 2. Describe the institutional and legal environmental factors controlling the operation of the target mine. The mine operates in the Hocking River Basin of Ohio and in the Wayne National Forest, the State of Ohio has reclamation and water quality laws for which there are several exceptions for the Hocking River area, mainly because of the enormous impact of abandoned and deserted mining operations. The Forest Service owns surface but not mineral rights for most of the Wayne National Forest. Reclamation requirements are similar to state requirements including a bond to cover reclamation costs. The mine pays for value of timber destroyed in the mining process. Forest Service Reclamation bond cost was \$150 per acre (net) in 1970 and timber costs averaged \$100 per acre in 1970. In most cases, the mine can delay reclamation, with the argument that they are returning to strip deeper seams.

OBJECTIVE 3. Define the coal market and demand schedule of the target mine. Market conditions are such that the target mine has a practical market area of about 50 miles radius (controlled by truck haul cost). In this area, the dominant coal user is a steam electric utility which buys approximately one-half of its coal from one large supplier on a long-term (30 year) cost plus fee contract, and one-half of its coal from small producers on the spot market with 30 day contract being the rule. Price is set by negotiation with large producers, except under conditions typical of 1973 and later where spot market has climbed to 2 or 3 times the contract price. In the spot market, a classic competitive environment is maintained since no single producer can affect price. Environmental regulation costs typical of the large producer can be passed through the long-term contracts but sufficient margins may not be available to small producers if average environmental management costs are higher due to scale economies. Thus, the demand schedule confronting the target mine is infinitely price elastic and set by forces outside its control. The target mine economic decision is simply how much to produce at the given market price.

OBJECTIVE 4. Estimate the target mine supply schedule and shifts due to water quality management technology. The supply schedule was estimated for the 11 year financial records of the firm. Average cost functions are of the type:

$$AC = X_1 + X_2 + u$$

where X_1 = tons produced each month

$$X_2 = X_1^2$$

u = residual

Four water quality management techniques were conceptualized and their costs estimated:

1. Mobile Neutralization Facility

First Costs \$2,000

Annual Costs \$2,333

Cost per ton \$0.073

2. Water Diversion

First Costs N/A

Annual Costs \$7,060

Cost per ton \$0.22

3. Water Diversion and Ponding

First Costs N/A

Annual Costs \$8,055

Cost per ton \$0.251

4. Package Treatment Plant with Sludge Disposal

First Costs \$107,217

Annual Costs \$2,878

Cost per ton \$0.09

Long Run Cost Functions. In the 11 years 1960 through 1970, profits summed to about \$48,000. Production averaged between 30,000 to 40,000 tons per year. Economies of scale exist which would suggest adding another shift or buying larger excavation equipment could result in higher net profits. However, some conditions mitigate against this tactic. Larger output require larger acquisition of mineral rights and a direct confrontation with the larger firms which block out the most favorable mineral rights. Additional employment would tend to encourage unionization efforts. The existing company is staffed by five members of the owning family with a few additional employees. This is the style of operation desired by the management.

Summary and Conclusions

The firm can accommodate a performance criteria in water quality management but probably not a technology-specified criteria. Technique 1 is believed to be possible and practical. Techniques 2 and 3 are too expensive to permit continued operation of the mines. Technique 4 appears to be economically feasible but would generate serious capital acquisition and maintenance problems.

WATER REUSE

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PLANNING FOR WATER REUSE

One prediction is certain: the future demand for water in the United States will continue to increase while the supply will remain relatively fixed. In 1970, the United States withdrew 365 bgd (billion gallons per day) of which 87 bg were for consumptive uses.¹ The estimated average annual streamflow in the conterminous United States is approximately 1,200 bgd² and it is doubtful that this amount will be greatly changed in our near future of 10, 20, or 50 years.³ Hence, the rate of change in demand will determine the nature of our water resource management problems.

As the process of urbanization continues, a large demand for water within a relatively small area will add to the pressure for greater efficiency in the present use as well as create intense competition for the presently available supply, e.g., water for our urban population versus the demands for irrigation. Based upon one set of projections,⁴ the relative importance of consumptive, municipal use is expected to increase while withdrawal uses will remain approximately the same. In 1965, our urban areas consumed 5.2 bgd representing 7 percent of the total consumptive use: by 2020, consumptive use in urban areas is expected to rise to 24.6 bgd, accounting for 16 percent of all consumptive use. Whereas withdrawal use for cities is projected to rise from 27 bgd in 1970 to 74.3 bgd in 2020, the proportion it represents of all withdrawal-uses is seen as remaining approximately the same (7 percent) or even possibly declining (5 percent)--primarily because of expected efficiency in water use and a threefold increase in demand for water for cooling in electric power generation.

As demand for water increases, shortages will be most acute in our urban areas. Cities are faced with the prospect of having to import water from distant sites. As sites for new reservoir construction become increasingly scarce and resistance to inter-basin transfers grow, new policies will necessarily be formulated and implemented. Again, we rely upon the final report of the National Water Commission:

To increase efficiency in water and use and to protect and improve its quality, and to do these things at least cost and with equity to all parts of our country . . . require major changes in present water policies and programs.⁵

However, in response to the increase in demand, cities have traditionally chose to increase the available supply. Except under emergency conditions, such as drought, alternatives that would lower demand have been ignored. For example, the most common response of 48 Massachusetts communities during the drought of the early 1960's, aside from the unenforced pleas for restrictions on water use, was to plan for increases in supply, new sources, improvements in present supply, emergency sources, and a cloud seeding experiment.⁶ Those adjustments directed toward a reduction of demand were rarely considered or adopted.

This traditional reliance upon technology designed to modify the environment, instead of policies directed toward changing our schedule of demand, has been equally pronounced in another water resource problem. White has succinctly noted that ". . . For a long time it was out of the question for a planning officer to study any way of dealing with flood losses other than by constructing engineering works or by providing relief."⁷

THE CHOICE OF ALTERNATIVES

Among the range of alternatives available for coping with urban water resource problems, the reuse of renovated wastewater is a potentially attractive choice. However, it is not to be considered the panacea for all future urban water resource planning problems; instead, water reuse should be considered as one alternative in combination with other adjustments in balancing the supply of and demand for water for our ever-increasing urban areas. Although the implications and potential of reuse is the substantive focus of this report, we reiterate the need in municipal water resource planning for a thorough consideration of each available alternative. Following a review of the alternatives for balancing supply of and demand for municipal water supply, we will direct our attention to those factors affecting the planning and adoption of recycling renovated water.

MODIFY WATER SUPPLY

The major source for municipal water supply in the United States, accounting for 75 percent of total capacity, is water from the diversion of rivers and streams (Table 1). Recent projections indicate that surface water flows will represent a slightly higher proportion of the total water used to satisfy future demands. However, as urban areas have grown, streams nearest to the cities have been developed and future opportunities for diversion are becoming more scarce. Among those regions in the United States that are more susceptible to a shortage of water, interbasin transfers are required.⁸

Transfer of water can be expensive. The economic, political, environmental and technological difficulties increase with the length of transfer required. The area in which the water originates, the donor region, is usually rural and often with a higher incidence of individual well users. There is a tendency to regard the water as belonging to the region and to view its transfer as necessary only because of unreasonable use by profligate urban water users.⁹

Groundwater, which currently represents 25 percent of total municipal supply, is expected to decrease slightly in proportion to the use of surface water.¹⁰ Sources capable of sustaining high withdrawal rates are limited in distribution, and while groundwater is the predominant source of self-supplied individual users, most major cities using groundwater do so as a supplement rather than as a sole source of supply.

Desalinization and weather modification are other potential sources which may, in selected circumstances, serve to augment conventional supplies. Although highly variable, weather modification in some instances has considerable potential, such as increasing snow pack, and subsequently, spring runoff during years when winter reservoir storage is low. Desalinization, on the other hand, is comparatively expensive, requires large amounts of energy, and is most promising on a small scale in unique situations.¹¹

Although efforts to reduce seepage and evaporation have had little success, reduction of water loss by identifying undetected leaks can be

TABLE 1

ALTERNATIVES FOR BALANCING SUPPLY AND DEMAND FOR MUNICIPAL WATER SUPPLY

Do Nothing	Modify Supply	Modify Demand
1) Accept Shortage Unplanned rationing	1) Increase Supply Divert New Streams Provide Increased Storage Use Ground Water 2) Increase Efficiency Reduce Reservoir Evapora- tion Eliminate Leaks Increase Runoff Reduce Evaporation 3) Weather Modification 4) Desalinization 5) Renovated Wastewater Non-potable Uses Potable Uses	1) Restrictions 2) Price Elasticity Peak Pricing, i.e. Peak Summer Pricing Marginal Cost Pricing 3) Meters 4) Educational Campaign Emphasizing Water Use Conservation 5) Technological Innova- tions and Application, e.g. Changes from Water Cooling to Air Cooling

substantial: in some cases as much as 15 percent of the water withdrawn may be unaccounted for because of leakage.¹²

MODIFY DEMAND

Although other alternatives are available and practicable, planners traditionally have seen supply as the variable in the supply-demand equation. Whereas price has been shown to be a significant variable, it is usually disregarded as a method of controlling demand.¹³ Marginal efficiency theory in Welfare Economics suggests that marginal costs should equal price; however, the decreasing block-rate pricing system, which is common to most cities, encourages high water-use and prices the last gallon of flow, which has most often been the most costly, at the lowest price. Increasing block rates, peak-summer pricing, and yearly-rate changes based on the supply in storage have all been proposed as methods of reflecting marginal cost in the pricing of water.

Rationing and restricting uses have been used as a management tool predominantly during crises--periods of drought. However, while the cost to consumers during periods of water restriction have been low, it is usually not regarded as a method of planning for water supply.¹⁴ In one city, the prohibition of using once-through cooling water was an economic benefit to industries which installed cooling towers and consequently saved in water bills more than the costs of the investment in recirculating equipment even when a discount rate of 20 percent was used.¹⁵

Little evidence is available to evaluate the effects of encouraging the public to reduce the amount of water consumed. The available evidence suggests, however, that such pleas were largely ineffective during the drought of the early sixties in the Northeast.¹⁶

Renovation and reuse of municipal water is neither a new concept, nor is it an inherently efficient method which should be employed to supply water. It can be inadvertent and unplanned as the withdrawal and use of water from a river with upstream users. For example, on the average, approximately one-third of the population in the United States

rely upon municipal withdrawals from streams containing one gallon of previously used water for every 30 gallons withdrawn; and, in some instances, the ratio of previously used water is as high as one-fifth.¹⁷ Likewise, Koenig suggests that of the water withdrawn for municipal supply, up to 18 percent was effluent.¹⁸ Or, water reuse can be direct and planned, as in a factory where water from one process is directed with or without treatment to a second in a series of cascading uses. In the municipal system, planned reuse involves the collection and treatment of sewage and the use of the effluent for irrigation, recreation, industry, or for return directly through an intervening body of water or aquifer for general municipal use.¹⁹

At the Federal level, the potential for water reuse has long been recognized by such groups as the Senate Select Committee on National Water Resources in the early 1960's.²⁰ In 1965, the Water Resource Planning Act required that reuse be considered one of the alternative methods of meeting future demand for water.²¹

Likewise, the Federal Water Resources Council recognized the potential value of reuse:

The large withdrawals estimated for 2020 in relation to run-off indicate that even with increased in-plant recycling a large increase in reuse would be required.²²

In the final report, the National Water Commission recommended that the reuse of renovated wastewater ". . . should occupy a prominent spot in future planning for overall water resources utilization."²³

THE PRACTICABILITY OF REUSE

Any consideration of the practicability of recycling renovated waste water for municipal supply will necessarily require answers to three equally-important questions. First, what are the risks to health for each specific water reuse project, especially if human consumption of the renovated wastewater would occur? Secondly, to what extent would a proposed water reuse project be socially acceptable: would the consumers accept reused water and would the politicians, public health officials and engineers provide their endorsement? Third, under what

conditions is water reuse an economically efficient alternative for municipal water supply?

PUBLIC HEALTH

Public health concerns are, for the most part, restricted to those uses in which drinking or bodily-contact is planned. There are at present, no cities in the United States processing effluent for direct potable reuse. Windhoek, South West Africa, has provided the only long-term example of direct introduction of effluent into the municipal supply. The sewage is treated to a tertiary level and includes a final filtration through activated-carbon before being mixed with the conventional surface flow. Up to one-third of the effluent in Windhoek is recycled for potable supply during periods when chlorine demand of the wastewaters is not excessive.²⁴ The water produced meets all of the standards set by the World Health Organization.²⁵ The favorable experience at Windhoek has led to the adoption of reuse for the water supply of Pretoria, the capitol of the Republic of South Africa.

From October, 1956, to March, 1957, Chanute, Kansas treated and reused water as a direct augmentation to the municipal supply. While the quality of the renovated water met the standards established by the U.S. Public Health Service,²⁶ the chemical composition deteriorated markedly and the water had a pale-yellow color, an unpleasant taste and odor, and foamed when it was agitated.²⁷ During the same period of drought another community, Ottumwa, Iowa, also recycled renovated waste water and no health problems were observed.²⁸

In Denver, Colorado, plans are being implemented to recycle renovated waste water for all uses including water for drinking. Currently a small demonstration plant (1 mgd) is under construction and a substantial research effort concerning water quality and health has been launched. Within ten years Denver may be recycling renovated waste water at the rate of 100 mgd.

In another experiment, Santee, California, developed recreational lakes from treated effluent with a particular focus upon the occurrence

of viruses and bacteria. Lakes containing the treated effluent served as a scenic background for picnicking; boating, fishing, and swimming activities were added later in successive stages. The swimming experiment was closely investigated and even though viruses were commonly isolated from raw sewage, none were ever measured in the input to a final contact chlorination process.²⁹

Although promising, the conclusions reached from these experiments should not lead to confidence concerning the relationship of health and the quality of renovated waste water. Bacteria and viruses appear to be controlled under proper filtration and chlorination, but little is known concerning the occurrence and distribution of heavy metals, such as chromium, mercury and lead, and organochlorine compounds, such as carbon tetrachloride, DDT, aldrin, dieldrin, and chlordane. Moreover, there is evidence which suggests that at least some organochlorine compounds are carcinogenic. The recently published study on the New Orleans, Louisiana water supply noted heavy concentrations of chloroform and carbon tetrachloride, both possible carcinogens.³⁰

The lack of definitive information on water quality and health should not preclude serious consideration of water reuse as a possible alternative in planning for municipal water supply. The same problems exist for nearly all other alternative sources of municipal water supply; and by not considering planned water reuse we are not increasing the assurance of the production of safe, potable water since most surface water sources contain substantial quantities of effluent and organic agricultural wastes. In nearly all communities in the United States, there are no routine tests for viruses; in fact, the U.S. Public Health Service's Drinking Water Standards have not yet established virus standards. The point is simply stated: the questions about health and water quality are unknown for both water reuse techniques as well as the currently operating conventional treatment technologies. Communities continue to focus upon bacteriological standards, tastes, and odors, while the effects of organics, heavy metals, and viruses are not measured and remain unknown.

However, conventional wisdom assumes that most water produced in the United States is safe to drink, and the implementation of water reuse would necessarily raise the risks to health. Harris and Brecher,³¹ when discussing conventional water supply systems, succinctly noted:

Almost everyone supposes that such systems are under continuous surveillance by competent state and local health officials, that water samples are scrupulously tested at frequent intervals, that any flaws in a water system will be soon discovered and corrected--and that the water we drink therefore must be safe. Unfortunately, almost everyone supposes wrong.

In a U.S. Public Health Service survey of 969 communities, "only 10 percent (of the communities) had bacteriological surveillance programs that met the 'criteria', while 90 percent either did not collect sufficient samples, or collected samples that showed poor bacterial quality, or both."³² And, 61 percent of the operators of the 969 communities ". . . had not received any water treatment training at a short-school level or higher."³³ Finally, in the same survey, only 59 percent of the communities produced drinking water that was acceptable under the recommended standards of the U.S. Public Health Service, standards that are considered by many to be lax when compared to those established by the World Health Organization. Similar results were observed in a more recent study of 446 United States' communities by the Comptroller General of the United States: 18 percent of the communities did not meet the standards, as measured by coliform, in two or more months during the preceding 12 months.³⁴

With the passage and implementation of the 1974 Safe Drinking Water Act,³⁵ enormous progress should be made towards improving the quality of our drinking water. With respect to the potential of water reuse, we would argue for a relativist perspective, rather than unattainable absolutist stance. With the completion of the Denver, Colorado water reuse project, the quality of the finished product will undoubtedly be significantly higher than the tap water presently available in most communities in the United States. This conclusion is not new. For example, Dean noted as early as 1965:

That we can make a better quality of water by treating sewage than is available in many of our cities. Controlled treatment of a known hazardous raw material can produce a safer product than routine treatment of a deteriorating source. Viruses can be removed from heavily polluted water by suitable treatment and the cost is not unreasonable.³⁶

Finally, the entire question of health is circumvented in those situations where water can be reused for purposes other than ingestion, e.g., industrial cooling, irrigation, and recreation. Indeed, it is these non-ingestive uses where reuse will most likely be adopted, but savings to the community might be foregone if water reuse is not also considered as a potential source for potable use.

PUBLIC ACCEPTANCE

Although renovated wastewater may be relatively safe to drink, a second and equally-important question concerns public acceptance, not only the consumers, but the politicians, management personnel, public health officials, and consulting engineers. In essence, no program utilizing renovated wastewater can be implemented without their acceptance.

Recalling the fluoridation debates and aware of the heightened public participation of the present day, water resource managers are particularly concerned about public acceptance of recycled wastewater. From an unpublished survey by Baumann of 300 municipal water managers in the United States in 1969, the most common reason cited by the 50 percent who opposed wastewater reuse was an anticipated rejection by the public. Similarly, Johnson found that "It would appear that water managers know very little of consumer responses concerning renovated wastewater, but generally consider the public would not accept it."³⁷

On the other hand, in a recent review of the literature, Baumann and Kasperson concluded that "there is little evidence to support the wide-spread conviction among those charged with proposing solutions to the nation's water supply problems that public opposition constitutes the most important obstacle to the adoption of wastewater reuse systems."³⁸ Moreover, there is evidence that the public will accepted renovated

wastewater for potable use provided they are aware of the technological characteristics of water treatment. Based upon survey data in five communities, Sims and Baumann suggest that what the consumers know and feel about drinking renovated wastewater is related to the individual's general level of education and his knowledge about water treatment and is not related to unconscious threats of specific concerns such as fear of contamination or beliefs concerning nature, technology, aesthetics, authority, progress, or destiny.³⁹

The recent experience in Denver, Colorado, supports these findings. In a survey of 500 people, the initial response to the concept of recycling renovated wastewater was primarily negative. However, as the respondents were provided additional information concerning the implications of water reuse planning, the rate of public acceptance increased until 85 percent of the respondents expressed a willingness to drink renovated wastewater.⁴⁰

In Windhoek, South West Africa, ". . . public acceptance has been very good."⁴¹ And although sales of bottled water increased in the Chanute, Kansas experience, the majority of the consumers drank the renovated wastewater.⁴²

The central question, then, is why do the managers and engineers perceive the public as unwilling to accept recycled, renovated wastewater when the available evidence suggests that the consumers would not be, in fact, an obstacle in community adoption of such a program. Could it be that a result of the process of professional socialization, the engineers, water managers, and public health officials are reluctant to innovate or change the established procedures of municipal water supply provision? Hence, the public becomes a scapegoat for their reluctance to consider and/or recommend a program of reuse? If so, a key obstacle in the consideration and adoption of alternative strategies of recycling renovated wastewater in municipal water supply planning may lie not so much in the minds of the consumer, as in the perceptions of consulting engineers and public health officials--two influential groups in community decision making in planning for municipal water supply. In another study by Sims

and Baumann,⁴³ 98 consulting engineers (33 firms) and 22 state public health officials (from 9 states) were interviewed concerning the practicability of a community program using renovated wastewater. It is public health officials who ". . . hold the more negative position--they begin by not liking the idea, then raise many and major objections to it, and in the end, find their reflection has strengthened their antagonism. Consulting engineers . . . begin with a far more favorable attitude, raise fewer objections and conclude with a perfectly even-split between endorsement and rejection."⁴⁴

SUMMARY AND CONCLUSIONS

Water reuse is a viable and attractive alternative for the provision of municipal water supply. While the demand for water continues to increase in the United States, particularly in our burgeoning urban areas, the traditional alternatives for municipal water supply planning may be less appropriate or no longer practicable.

From the perspective of public health, the growing evidence suggests that while new criteria may be necessarily formulated and applied to determining whether our water is safe to drink, and although new problems may emerge, for example, contamination by carcinogenic chemicals, these problems are not unique to the planned reuse of water. In fact, because of more sophisticated treatment techniques and monitoring of water quality, recycled renovated wastewater is probably less of an insult to public health than the water currently produced by most municipal systems in the United States.

If recycled renovated wastewater can be safe to drink, and under specific qualifications the concept is a socially acceptable and economically efficient alternative for municipal water supply planning, then why has the rate of adoption been so low? The answer may be related to the existence of two problems: the unavailability of a methodology to assess the relative value of reuse, and the professional biases of consulting engineers, public health officials, and municipal water managers. An effort has been made to correct the first deficiency: a simulation

model has been developed to evaluate the relative merits of specific water reuse systems. The second problem has been only defined and awaits additional research.

Water reuse should be integrated in the planning for municipal water supply. The thrust is no longer whether reuse is possible; instead, our attention should be directed toward programs and research on the diversity of opportunities for efficient implementations.

REFERENCES AND NOTES

¹The distinction between the two uses is as follows: withdrawal water is available for further use, while water consumed is not available for reuse since it is either lost through evapotranspiration or incorporated into the product; See U.S. National Water Commission, Water Policies for the Future. Washington, D.C.: U.S. Government Printing Office, 1973, p. 9.

²U.S. Water Resources Council, The Nation's Water Resources. Washington, D.C.: U.S. Government Printing Office, 1968, p. 1-22.

³We are assuming no significant change in climate, although planned weather modification efforts may be effective in selected local areas under unique atmospheric conditions.

⁴U.S. Federal Water Resources Council, The Nation's Water Resources, p. 8.

⁵National Water Commission, Water Policies for the Future, p. 1.

⁶Russell, Clifford S., Arey, David G., and Kates, Robert W., Drought and Urban Water Supply, Baltimore: The Johns Hopkins Press, 1970.

⁷White, Gilbert F., in Environmental Quality and Water Development, C. Goldmand, J. McEvoy III, P. Richardson (Eds.), San Francisco: W. H. Freeman & Co., 1973, p. 161.

⁸Wollman, Nathaniel and Bonem, Gilbert W., The Outlook for Water, Baltimore: The Johns Hopkins Press, 1971, p. 18.

⁹This is an attitude expressed commonly by groups such as S.O.S. (Save our Streams) in Western Massachusetts fighting the diversion to the Quabbin System; also, see: Marion Clawson, Suburban Land Conversion in the United States, Baltimore: The Johns Hopkins Press for Resources for the Future, 1973, p. 130.

¹⁰U.S. Bureau of the Census, Statistical Abstract of the United States, Washington, D.C., 93d edition, 1972, p. 173.

¹¹National Water Commission, Water Policies for the Future, p. 345.

¹²John Simmons, "Economic Significance of Unaccounted for Water," Journal of the American Water Works Association, LVIII (1966), pp. 639-641.

¹³The literature is extensive. See Charles W. Howe, "Municipal Water Demand," in Forecasting the Demands for Water, ed., by W. R. Derrick Sewell, et al. (Ottawa: Dept. of Energy, Mines, and Resources, 1968), p. 48.

¹⁴Clifford S. Russell, David G. Arey and Robert W. Kates, Drought and Water Supply.

¹⁵Ibid.

¹⁶Ibid.

¹⁷National Water Commission, Water Policies for the Future, p. 306.

¹⁸Koenig, Louis, Studies Relating to Market Projections for Advanced Waste Treatment, Washington, D.C.: U.S. Dept. of Interior Publication WP-20-AWTR-17, 1966.

¹⁹Examples of reuse applications are: Irrigation, Lubbock and San Angelo, Texas; recreation, Santee and South Lake Tahoe, California; aquifer recharge, Whittier Narrows, California; direct reuse, Windhoek, S. W. Africa.

²⁰U.S. Senate Select Committee on National Water Resources, Water Resources Activities in the United States, Washington, D.C.: U.S. Government Printing Office, 1960.

²¹Water Resources Planning Act of 1965 (P.L. 85-90). Sec. 102; also Water Resources Council, "Principles and Standards for Planning Water and Related Land Resources," Federal Register, XXXVIII, No. 175, Sept. 10, 1973, 24778-24869.

²²U.S. Federal Water Resources Council, The Nation's Water Resources, p. 1-23.

²³National Water Commission, Water Policies for the Future, p. 314.

²⁴Ibid., p. 313.

²⁵G. C. Cillie, et al., "The Reclamation of Sewage Effluents to Domestic Use," Third International Conference on Water Pollution Research (Washington, D.C.: WPFC, 1966); also G. J. Stander, "Water Reclamation in Windhoek," Scientiae, X (January, 1969), pp. 3-14.

²⁶U.S. Public Health Service, Drinking Water Standards, Washington, D.C.: Government Printing Office, 1962.

²⁷Metzler, Dwight, et al., "Emergency Use of Reclaimed Water for Potable Supply at Chanute, Kansas." Jour. American Water Works Association, 50 (1958), pp. 1021-1057.

²⁸U.S. Senate Select Committee on National Water Resources. Water Resource Activities in the United States: Present and Prospective Means for Improved Reuse of Water, 86th Congress, 2nd Sess., Print No. 30. Washington, D.C.: Government Printing Office, 1960, p. 3.

²⁹Merrill, John C., et al., The Santee Recreation Project, Cincinnati, Ohio: Federal Water Pollution Control Agency, 1967, pp. 108-116.

³⁰Marx, Jean. "Drinking Water: Another Source of Carcinogens," Science, 186 (Nov. 20, 1974), pp. 809-811.

³¹Harris, Robert H. and Edward M. Brecher, "Is the Water Safe to Drink," Consumer Reports, 39 (June, 1974), p. 437.

³²U.S. Public Health Service, Community Water Supply Study, Washington, D.C.: U.S. Public Health Service, 1970, p. vi.

³³Ibid., p. 8.

³⁴Comptroller General of the United States, Improved Federal and State Programs Needed to Insure the Purity and Safety of Drinking Water in the United States. Washington, D.C.: General Accounting Office, B-166506, 1973.

³⁵Safe Drinking Water Act, 93rd Congress, S. 433 and H.R. 1059.

³⁶Robert Dean in Berg. (ed.), Transmission of Viruses by the Water Route, New York: John Wiley and Sons, 1965, p. 470.

³⁷James F. Johnson, Renovated Waste Water: An Alternative Supply of Municipal Water Supply in the United States. Chicago: University of Chicago, Dept. of Geography Research Paper No. 135, 1971, p. 92.

³⁸Duane D. Baumann and Roger F. Kasperon, "Public Acceptance of Renovated Waste Water: Myth and Reality," Water Resources Research, 10 (August 1974), p. 673-674.

³⁹ John H. Sims and Duane D. Baumann, "Renovated Waste Water: The Questions of Public Acceptance," Water Resources Research, 10 (August 1974), pp. 659-665.

⁴⁰ Heaton, R. D., Kinstedt, K. D., Bennett, E. R., and L. G. Suhr, "Progress Towards Successive Water Use in Denver," unpublished paper.

⁴¹ National Water Commission, Water Policies for the Future, p. 313.

⁴² Dwight Metzler, et al. "Emergency Use of Reclaimed Water for Potable Supply at Chanute, Kansas," Jour. American Water Works Association, 50 (1958), pp. 1021-1057.

⁴³ John H. Sims and Duane D. Baumann, "Professional Bias and Water Reuse." Submitted for publication.

⁴⁴ Ibid.

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Holcomb Research Institute

MUNICIPAL REUSE OF WASTEWATER

Any consideration of utilizing reuse should start with the concept of an integrated system, integrated both in management and in the distribution of water, so that either treated effluent or potable water could be furnished to non-potable users. With this control, the managers could make a decision based on his judgment of the state of the system, to produce and distribute treated effluent or to use only the potable supply for all users. This would eliminate the unnecessary costs in production and distribution of effluent during periods when unused capacity exists in the potable water supply.

In general, there is a relationship between reuse and storage of flows which provides a guide to using treating effluent: reuse systems cost less to build, but are more expensive to operate than systems designed to divert and store flows. On the other hand, reservoir systems are expensive, but have low operating costs which suggests that reuse systems should be used only when water from storage is unavailable to meet the demands. In this way, reuse would function as a source of peak supply while storage with its low operating costs would provide the necessary continual capacity. However, there are limitations. Treated effluent is not usually considered to be acceptable as a source for potable supply and would be restricted to those users previously identified and furnished with a separate distribution system for non-potable effluent. These limitations, however, only serve as constraints on the realization of the full potential of the system.

Reuse, no matter how it is used, provides a source of water which can delay or obviate the need for conventional additions to supply. In addition to supplying water, the presence of reuse as a standby source, not affected by periods of low-flow, can increase system yield and provide planning flexibility by serving: (1) as a substitute for the high levels of assurance required in municipal systems; (2) as a means of mobilizing any over supply in the system; and (3) as a means of shortening the planning cycle which would allow pragmatic evaluation of change in demand to replace present long-term projections.

REUSE TO SUPPLY ASSURANCE The yield of a water supply system based on storage of flows is usually expressed as a quantity of water available or assured ninety-five percent (or more) of the time. To achieve this level

of assurance, some storage must be provided which will be required less than 5 percent of the time. There is an inverse relationship between assurance and yield; yield increasing as assurance declines.¹ By allowing the levels of assurance in a system to be relaxed, the yields withdrawn from the system could be increased, and reuse could furnish the additional water necessary to maintain the desired levels of assurance.

MOBILIZING EXCESS SUPPLY While the yield of municipal systems is always calculated to provide high assurance levels, there is indication from cities, which have been forced to restrict water because of drought, that rationing or restriction of water causes little damage. There is, however, an indication that even a shortage less than 5 percent of the time is not acceptable to engineers. Engineering and reference handbooks urge conservative calculations. Social scientists, on the other hand, claim that yields are often if not always, understated. As an alternative to this sometime academic debate, renovation and reuse can provide a standby source which will allow the use of the present facilities until pragmatic evaluations of the response of the physical system to the demands placed on it can replace the engineering estimates of yield.

SHORTENING THE PLANNING CYCLE The long time required for the development of new water sources requires long-term estimations of the future demand for water. In the past, there was little concern if the future demand had been overstated and if subsequent projects based on this inflated demand had resulted in temporary oversupply. The rapid growth in the use of water utilized any excess capacity. There are indications that the rapid growth in demand has slowed. Some factors, such as the low rate of births and the replacement of the single family house with apartments and cluster homes, indicate that the present slowdown will continue. Excess capacity added now under lower rates of growth will be utilized more slowly with a consequent investment in idle-capacity for a longer period.

FACTORS AFFECTING ECONOMIC FEASIBILITY The present method of evaluating the economic efficiency of reuse by comparing the costs of both reuse and an alternative supply is misleading. The important consideration in any economic analysis is the cost at the margin. If two systems of supplying water have the same average costs and reuse is considered as a supplement to both, an average cost analysis of the operations of both systems would result in the same findings. If, however, there was no excess capacity and

the alternative was the addition of storage, providing reuse might be a more efficient economic solution. Calculation of the costs of the final unit of water delivered in a system with and without reuse should be the criterion of any evaluation of the system.

Evaluation of reuse should not stop, however, with considering the two alternatives: reuse and conventional supply. The analysis should be extended to include the method of operating the reuse facility to provide more optimal long-term solutions to meeting the demands for water. In such an analysis, reuse should be considered as one of the methods of supply along with surface and ground water. Such an analysis should also consider the demands for water. The manager should be encouraged to manipulate any one of the four components, ground water, surface water, reuse, and demand to achieve the most efficient system for the specific year and for the entire planning period.

Evaluating alternative proposals for municipal supply planning is a complex problem. The number of variables is large and calculating solutions for a number of possible streamflows which might occur during the planning period is beyond the possibility of a deterministic analysis.

Even if such an analysis could be done, it would represent a unique solution--an assumed set of population growth and stream flows. What is more helpful is a range of solutions representing some distribution of probabilities that any individual set of conditions might occur.

In order to evaluate the use of municipal wastewater, a computer model was developed to simulate the supply and storage of surface and ground water, the demands by a number of water-using sectors and the treatment of sewage by secondary and advanced waste treatment processes (Fig. 1).¹ To test this model, the water supply system of Colorado Springs, Colorado was simulated. Streamflows and rainfall were generated using the program HEC-4 provided by the Hydrologic Engineering Center of the U.S. Army Corps of Engineers.² Water demand models were based on multiple regressions of 12 years of monthly demand for 5 sectors of use: residential, commercial, industrial, military, and municipal.

COLORADO SPRINGS, COLORADO The water supply system of Colorado Springs is a

¹Lef, G.O.G. and Hardison, C.H. "Storage Requirements for Water in the United States," Water Resources Research, 2, 1966, pp. 323-354

²U.S. Army Corps of Engineers, Hydrologic Engineering Center, HEC-4 Monthly Streamflow Simulation, Davis California: The Hydrologic Engineering Center, 1971.

complex network utilizing ground water, surface water, and renovated water from returned sewage. Twenty reservoirs, some for the non-potable system, provide for the storage and release of water. The doctrine of prior appropriations governs the amount and timing of diversions from streams and the storage and reuse of water.

The areas served by the water system have been growing rapidly both by natural population increases and by the annexation of the surrounding water systems. In the decade from 1960 to 1970, the population of the SMSA, which includes Colorado Springs, increased 64 percent. To meet the demand, the water system has expanded rapidly from less than 10,000 acre-feet in 1960 to over 30,000 acre-feet in 1973, including the capacity to provide 3,600 acre-feet of renovated effluent. Secondary effluent is further treated either by filtration to produce irrigation water or by coagulation, sedimentation, and carbon filtration to produce water for industrial use. Present plans are for additions which will bring the total yield from all sources up to 97,000 acre-feet (Table 1). This plan for increasing the capacity at fixed times was simulated.

An alternative to the above plan was also simulated. The alternative provided no reuse capacity at the beginning of the simulation and made the addition of the Eagle-Arkansas and Homestake projects contingent on a decision process based on monitoring reservoir level, streamflow, and water use. In both the plan and the alternative, renovated water was restricted to non-potable uses.

RESULTS OF THE SIMULATION Both the plan and the alternative were simulated for three streamflow series differing from one another in the frequency, timing, and duration of droughts. The simulations were run for three assumed levels of population growth (Fig. 2).

Under the assumptions of high population growth, the plan could not support the demands of the system over the 50 year planning period. Using three different sequences of streamflows, the plan failed after 33, 34, and 36 years. The alternative, however, supported demands for the full 50 year period. Moreover, the addition of two water supply projects was delayed an average of 16 years. The necessary capacity of the reuse plant was nearly

TABLE 1
FUTURE ADDITIONS TO THE WATER SUPPLY SYSTEM

Year	Plan	Yield (acre-feet)
1977	Eagle-Arkansas	5,000
1979	Homestake (2nd phase)	17,000
1985	Fryingpan-Arkansas (2nd allotment)	10,000
	TOTAL	32,000
1979	Reuse	4,000
1983	Reuse	5,500
	TOTAL	9,500
	GRAND TOTAL	41,500
	Present capacity	56,200
	Present and future total	97,700

Source: Colorado Springs, Colorado Water Division records.

three times as large as required for operating the plan but was not required until later. The amount of water reused was higher than scheduled in the plan only during the fourth decade. The present value of operating the plan (using a 6.875 rate of discount) averaged \$21 million, compared with \$12 million as the average cost of the alternative.

The medium and low population growth cases resulted in lower costs for the alternative, but the plan, depending on a fixed schedule of investments and requiring a predetermined quality of reuse, was isolated from the lowered demands of the system and required the same \$21 million investment (Table 2).

For every assumed population and streamflow simulated, the alternative was a less costly method of supply than the plan. Of the two modes of providing water for Colorado Springs, the plan is least desirable under conditions of low population growth.

The alternative is economically a more efficient method of providing water supply for Colorado Springs. The additional expense of the plan arises from the cost of treating effluent when it is not required and from premature investment in both conventional and reuse facilities.

Figure 1
FLOW DIAGRAM OF THE MODEL

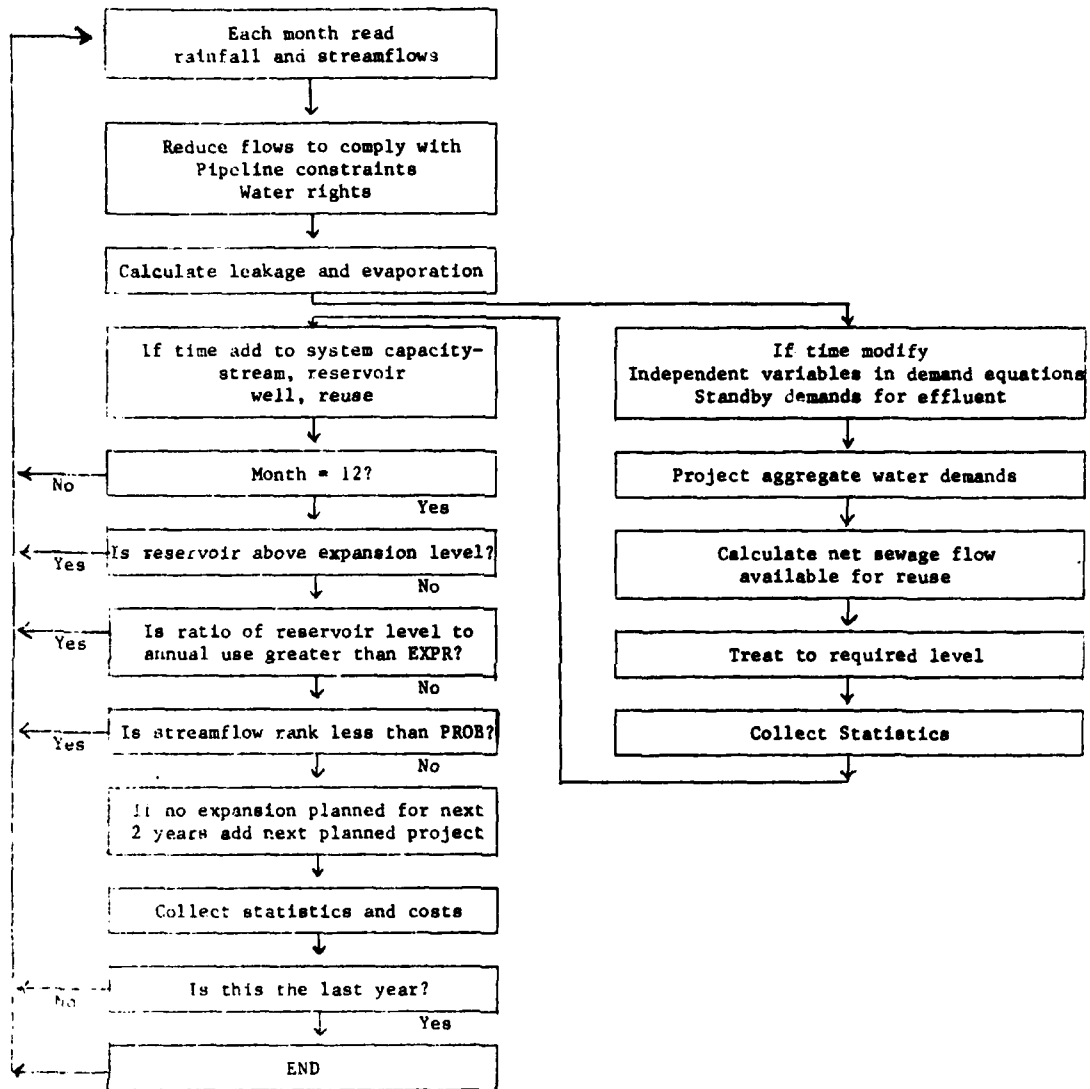


TABLE 2
SUMMARY OF SIMULATIONS: HIGH, MEDIUM, AND LOW
POPULATION ASSUMPTIONS; STREAMFLOW SERIES I

	PLAN 1	High Population	ALTERNATIVE Medium Population	Low Population
Years of projection	50	36	50	50
<u>Capacity of Reuse Plant</u> (Maximum)				
Decade 1	12	0	0	0
2	12	26.4	0	0
3	12	27.4	11.9	9.7
4	12	32.0	11.9	12.8
5	12		11.9	16.8
<u>Reuse Water Processed</u> (acre-feet)				
Decade 1	19,000	0	0	0
2	40,000	7,000	0	0
3	40,000	10,644	1,400	700
4	40,000	40,107	0	1,500
5	40,000		0	2,100
<u>Additions to Capacity</u> (Year)				
Fryingpan, Arkansas	1985	1985	1985	1985
Eagle, Arkansas	1977	1993	1998	2013
Homestake	1979	1998	2000	never required
<u>Present value of</u> <u>investments</u> (millions of dollars at 6.875 percent)				
Reuse Capacity	2.20	1.91	0.7	0.6
Reuse operations and maintenance	4.44	1.69	0.4	0.8
Conventional Capacity	<u>14.50</u>	<u>7.17</u>	<u>6.5</u>	<u>4.6</u>
	21.50	10.77	7.6	6.0

¹ These figures are for 50 years of operation of the PLAN. There is a little difference, less than a million dollars, in operation of the PLAN for less than 50 years.

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Interpreting Public Attitude Toward Water Reuse

Those psychological characteristics - values, attitudes, psychodynamics - that distinguish a given professional group, do not appear by chance; there is a logic to them. Persons and professions seek each other out, first for training, then for practice. That is, professions attempt to select persons whose psychology is in harmony with their defining tasks, their social structure, and their ideology. Conversely, persons attempt to select professions the nature of whose work, social structure and value system they perceive to be in harmony with them, that is, with their personalities. Thus, persons become professional apprentices or trainees because both they and their trainers anticipate man and job will be well suited. And the training period is used by both parties to test that relationship, and to increase the degree of "fit." As a result, a professional is far more than an expert by virtue of specialized knowledge; he is a man cut from a certain cloth - identifiable not only in terms of information and skill, but in his ways of perceiving and thinking, in his feelings, his beliefs, in his loyalties and his prejudices.

Little research has been done concerning the psychology of those professionals whose work involves them with environmental problems; rarer still is the study which explores how the psychological characteristics of such groups might influence their work with such problems. As an example of how crucial this influence might be, let us take a brief look at a study of how consulting engineers and public health officials perceive the persons and processes that would be involved in a community decision concerning a specific environmental issue - the use of renovated wastewater.

Because we were interested in identifying the unpremeditated feelings and attitudes of these two groups of professionals, as well as their thought-through professional opinions, we used a projective test as a device for initiating discussion of the problem. Respondents were shown a picture in which seven adult men in business dress are grouped in various attitudes around a conference table. They were given these instructions:

This is a picture of a meeting in a mayor's office which he has called to discuss the possibility of coping with an impending local water shortage through the use of reclaimed wastewater. I would like you to use your imagination and tell me a story about it. Who do you think are the various persons attending the meeting? What is going on at the moment? What are the men thinking and feeling and saying? How do you think this situation will turn out?

The first question we want to ask of the stories the men told is who did they see as attending the meeting? That is, what interests are represented, what professions have members present, and indeed, who has been left out?

Out of 12 ranked categories of persons identified as being present at the meeting, the first 8 are either executive-administrators or professional experts: the mayor, a member of the city council, a consulting engineer, a public health official, a water works superintendent, a member of either the mayor's or the city engineer's staffs, and a legal counsel. Overwhelmingly, the respondents restrict membership in the decision-situation to government officials and their professional consultants. Rarely are non-elected representatives of the public (such as heads of community organizations) or representatives of business and industry (such as the Chamber of Commerce) mentioned. Apparently, there is the conviction that the question of a solution to an environmental problem should be left to them, as experts, and to public officials. The people themselves - both the general public and organized public groups, are left out. This de facto exclusion fits with the disdain and fear of public opinion that is found to be characteristic of professionals.

Now that we know who is involved in the meeting, we can ask what went on? That is, who took what position on the question of using renovated wastewater and why; who was for and against and what were their reasons?

Both professional groups are in complete agreement in their perceptions of themselves, each other, politicians and the public. The consulting engineer is seen as the person most favorably disposed toward the reuse project (54 percent), the public health official as most opposed (58 percent), and the mayor as most neutral, undecided, or equivocal (76 percent). These assignments of a preponderant position contrast sharply with the perception of "The Public" which is seen as being more evenly distributed between positive (25%), negative (48%), and undecided (24%) attitudes. Clearly, both the engineers and health officials are far more certain of themselves and their professional brothers than of the unknown layman -- at least insofar as the initial response to the idea of using renovated wastewater.

We have seen that the majority of both consulting engineers and health officials perceive themselves to be in opposition to one another. But these are general attitudes; what are the specifics, the causes (or rationalizations) of their positions? What are the distinguishing concerns of each professional group?

It is interesting that the professional sample most favorable to the idea of using reclaimed wastewater -- the consulting engineers -- is, at the same time, the group which finds it personally most repugnant: 46 percent of them admit to feelings of revulsion, and it is their first-ranked concern. The next problems most frequently seen by engineers are three: unfavorable public reaction (28 percent), health issues (22 percent), and technical feasibility (24 percent). This last figure is surprising; only a fourth of the engineers raise questions concerning their own area of expertise -- the technical problems involved in direct potable reuse.

The same logic suggests that public health official also respond somewhat unexpectedly -- health issues involved in the use of renovated wastewater are not their first concern, that rank goes to their worried interest in what the public reaction will be (55 percent). And indeed, their anticipation that the public may "cause trouble" is shown again in their concern about such a program's possible political consequences, an idea expressed with equal frequency (46 percent), to that of their concern for health issues (46 percent).

In sum, the two professional groups contrast greatly in the issues discussed at the meeting in the mayor's office. Engineers have but one single concern of first magnitude -- that of expressing (and controlling) their feelings of revulsion to the use of renovated wastewater. While they acknowledge the problems of technical feasibility, public response and health, they do not emphasize them. Public health officials, on the other hand, are primarily concerned with three questions, of which health safeguards is but one; first and foremost, is their anxiety over public response and political repercussions.

We can now ask a third and final question of the stories: what is the meeting's final accounting? After the positions have been argued, who "votes" which way? The groups' concluding attitudes are much like the initial ones: twice as many consulting engineers (39 percent) as health officials (18 percent) favor the idea, and virtually twice as many health officials (68 percent) as engineers (38 percent) oppose it. What has happened in the course of the meeting is a shift toward a negative view; originally 54 percent of the engineers were favorable disposed toward the water reuse proposal and only 58 percent of the health officials were opposed. This movement is probably best viewed in the light of professional conservatism -- the well-known tendency of the invested professional to avoid the risks of change and to preserve the known and controlled status quo in his area of expertise.

Nevertheless, the interprofessional differences that appear here are considerable. More than two-thirds of the health officials (86 percent) are against the use of renovated water, only 18 percent of them are for it, and then for the "crisis time only." This contrasts sharply with the final attitudes of the consulting engineers -- as many of them are for it (39 percent) as against it (38 percent).

These differences are surely best understood from the differing perspectives of the two professions' areas of concern and their correlative differences in training. Consulting engineers are not directly involved with questions of public response or politics; their primary interest and responsibility is with the technical -- its possibility and practicality. The public health official, on the other hand, is by definition responsible to the public. He must be concerned about its response. And further, the potential consequences of his approval of a program to use renovated wastewater are far more threatening. The spectre of a possible widespread disaster must loom large in strengthening

the health official's resistance to an unfamiliar system. His risks are far greater than those of the engineer.

We see then, that in telling stories about a hypothetical situation in which city authorities invite experts to consult with them on the possibility of a community program using renovated wastewater, consulting engineers and public health officials reveal their initial attitudes toward such a proposal, their perceptions of what problems might be encountered, their own personal concerns, and finally, their considered professional stance. The data suggest strongly that when you ask for an expert's opinion, you get far more than you bargained for, far more, that is, than his purely expert judgment. You also get his professional fears and prejudices.

Perhaps the most important insight into the thinking of these two groups of professionals is their convictions that the public will reject renovated water for such intimate uses as bathing, cooking and drinking.

Such conviction rests on two related bases: first, there are prior unpleasant experiences, such as the public response to land treatment of sewage or, longer ago, to fluoridation. Second, there is ignorance, that is, an absence of hard data concerning public response to such uses of recycled water. Given this combination of factors, engineers and public health officials, do what all reasonable men do under such circumstances -- they generalize, and follow the wise and defensive logic of "fool me twice, shame on me."

But such a process, while understandable, can be dangerously misleading - for the trouble with traumatic experiences is that their material power gives them an influence over our conclusions they don't deserve. One doesn't want the child who's burned his finger on the toaster to refrain from touching anything more of metal.

The remedy is a deliberate and conscious attempt to remain open to those experiences - that many inductions were made too soon and based on too little.

Of course, there have been five or six studies done on public response to drinking renovated wastewater; indeed, Duane Baumann and I have done one. While they vary considerably in their results, all of them report a more positive public attitude than that anticipated by engineers and health officials.

I'm sure you now want to throw the ball of illogicity back to me, and accuse us, quite justifiably, of a conclusion based on untrustworthy data. For all of the studies are subject to the same criticism -- they are based on anticipatory behavior; in essence, the question they have posed is would you drink it, not do you drink it. And the distance between what one says he will do and what one will actually do is often to be calculated in light years.

Now, if this sounds like a plea for specific research funds, it may very well be. But, more than that, it is a plea for acknowledgement of the increasing need for behavioral science in water resource planning. Several speakers have been ardent in their emphasis on the critical role various publics play in resource programs -- whether it be Chicagoans stalled in a flooded underpass, or Indians robed in newfound ideological commitment. But I heard no explicit call for appropriate expertise. Somehow, the behavioral sciences tend to be seen as merely the exercise of common sense. And men who wouldn't think of exercising judgment over a matter of, say, pathogens in water - leaving that to the microbiologist - often do not hesitate to assume competence in psychology, sociology, and political science when dealing with public response.

Granted, interdisciplinary work is enormously difficult -- it is an arena where, by definition, professional socializations confront one another. And until you've experienced that, one has no idea of "wrong-headedness" of those who don't share your way of thinking at things. But I suggest there's no way out - more and more, the Corps has employed behavioral scientists, and more and more it will have to. The human factor is an unavoidable reality, not to be understood by an amateur....

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WATER DEMAND FORECAST

AND

ANALYSIS

ASSESSING THE AGRICULTURAL DEMAND FOR WATER*

Since the beginning of government planning for water resource development, economists have decried the use of the requirements approach or fixed coefficients for water use. The practice of assigning some fixed value per acre of irrigated land or per person is contrary to experience and logic. The amount of water that will be used depends on the price at which water can be obtained. The level of use and the elasticity of demand varies among uses and with the price level within uses. As an example, the elasticity of demand coefficient for water for drinking is very small (i.e., quantity taken varies little with price). On the contrary, the elasticity coefficient on marginal irrigated land where water is plentiful and liberally used is expected to be relatively high.

Very little has been done about this alleged lack of an adequate evaluation. The following items give evidence to the continuing problems. Economists have provided little data. Fixed coefficients were used in the framework studies but, of course, as was pointed out earlier by Mr. Karabotsas, these were an inventory of regional desires. The requirements approach lends itself well to a wish book. Irrigation (and other water supply) reconnaissance and feasibility studies use a water coefficient based on potential evapotranspiration to meet a maximum consumptive use. M & I studies usually base the water requirement directly on population.

* Jay C. Andersen, Professor, Economics Department and John E. Keith, Research Assistant Professor, Utah Water Research Laboratory, Utah State University.

It becomes necessary to estimate values of water in various uses because of a lack of a market for water. Institutional constraints of water law, water rights, compacts, and state, local, and federal interventions prevent a market from functioning. But, basically, the interdependence of individual actions and externalities would inhibit a market anyway.

Demands for water are mostly "derived demands". By that is meant that the utility or value or usefulness of water arises because of the production of something else. This in turn lends itself to calculation of value to the user or a value product estimate. This can be interpreted as "willingness to pay" on the part of a user. Some examples are in use of water to produce:

Agricultural crops and livestock products;

Water-based recreation activities;

Industrial products;

Lawns and gardens; and

Abatement of flood damages.

As a result of the "derived demand" concept, the demand schedule for water in most uses can be imputed by modeling the process of producing the product. Often this is done by "costing" out all costs other than water and leaving the "residual" or "surplus" values to water. Sometimes more accurate and sophisticated schemes are used to attempt to simultaneously impute values to all scarce resources in a production process. We have chosen the latter course.

Since irrigation presently accounts for over 90 percent of water diversions and consumptive use in Utah (and in much of the arid west), it was fairly easy to select that use of water for which we would begin

to derive demand (or willingness to pay) schedules. However, competing uses of water for industrial, municipal, and environmental purposes are increasing at a rapid pace. See Table 1. We have embarked on this program beginning with agriculture. Other areas may need to look at hydropower, navigation, or other uses.

Some background data on water use in Utah is useful for perspective. See Figure 1.

- a. Parts of the state where good arable land is available are very dry. Precipitation varies from about 3 to 20 inches, except in the mountainous areas where it may be 50 inches or more.
- b. Irrigation is the major water user mainly along the west slopes of the Wasatch Mountains in the Great Basin.
- c. Much of Utah's entitlement to the water of the Colorado River continues to flow downstream on out of the state.
- d. A major water production area in the state is in the northeast part of the state off the south slope of the Uintah Mountains.
- e. Major proposals for within state water transfer (called the Central Utah Project) are from the northeast to the northwest and west central parts of the state.
- f. Major water use proposals for energy are in the eastern portion in the Colorado Basin.

In order to estimate the most efficient interregional allocation of water and evaluate a method of proceeding, Utah has been divided into 10 approximately homogeneous drainage regions (hydrologic sub units). Six are in the Great Basin and 4 in the Colorado Basin. Some are potential exporters, some potential importers.

Table 1. Projected consumptive use of water for energy in Utah.

Use	Annual Use 1,000 acre ft/yr
Coal Gasification	200-900
Coal Liquefaction	100-650
Coal Fired Electrical Gen.	300-400
Oil Shale	100-200
Coal Pipelines	30-60
Coal Mining	14-23
Nuclear Power	10-20
Oil Refining	6-12
Total	700-2300

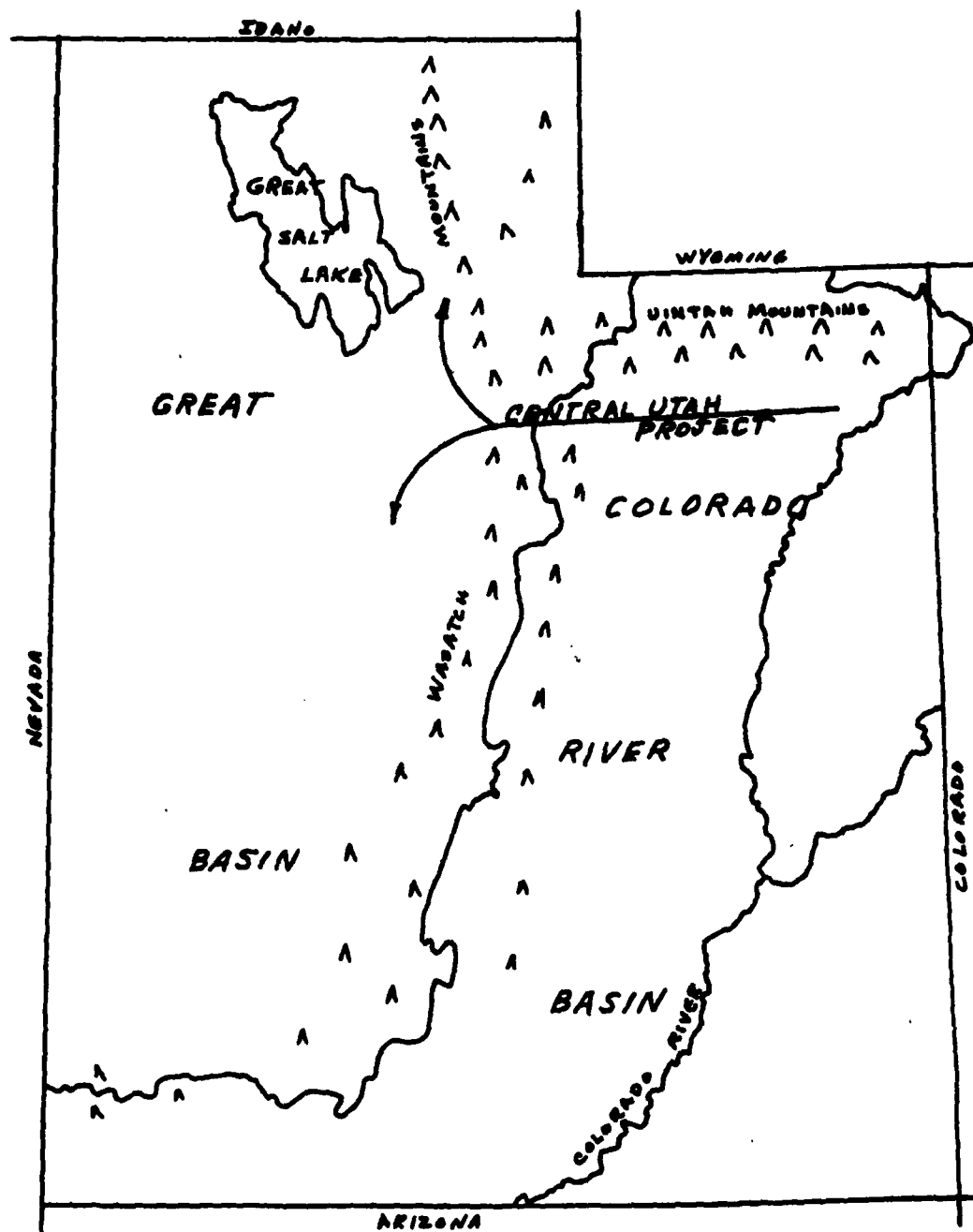


Figure 1. Major water features in Utah.

A first step was made by computing a least cost method of meeting fixed requirements for agricultural, M & I, and wetland uses of water. A linear programming model was used assuming certain quantities of water must be supplied to each of these uses in each hydrologic sub unit. Under these assumptions, the costs of using, storing and transporting water among regions was minimized, but this system had the usual faults of the requirement approach.

In estimating water demand, information on surface and groundwater supplies and the presently irrigated and potentially irrigable land according to land class was obtained for each county or portion of a county within each of the regions. Water use factors, crop rotation constraints, costs of production, yields, product prices, and costs of bringing new land into production were also estimated. These values were then used in a linear programming model to estimate a demand (marginal value product) schedule for water to be used in agricultural production within each region. See Figure 2. The amount of water made available to the production model for each hydrologic sub unit was varied so that the model created a shadow price (marginal value product) for different degrees of scarcity at each level. These were then combined to estimate the relationship between the quantity of water and its economic value (a demand schedule or function). Figure 3 is the demand schedule for one region. Figure 4 represents the demand schedules for all 10 regions superimposed on one figure. Elasticities which were computed by fitting regression lines to these demand schedules vary from -1.0 to -3.0. These indicate a relatively elastic demand.

The general conclusions from the study indicate that most parts of the state suffer from a water shortage in that more production could be

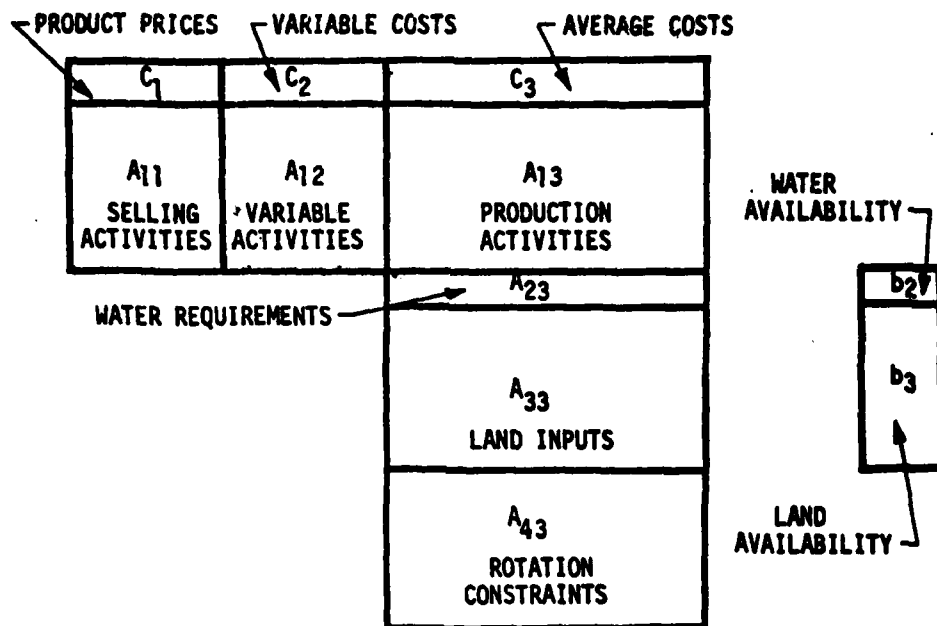
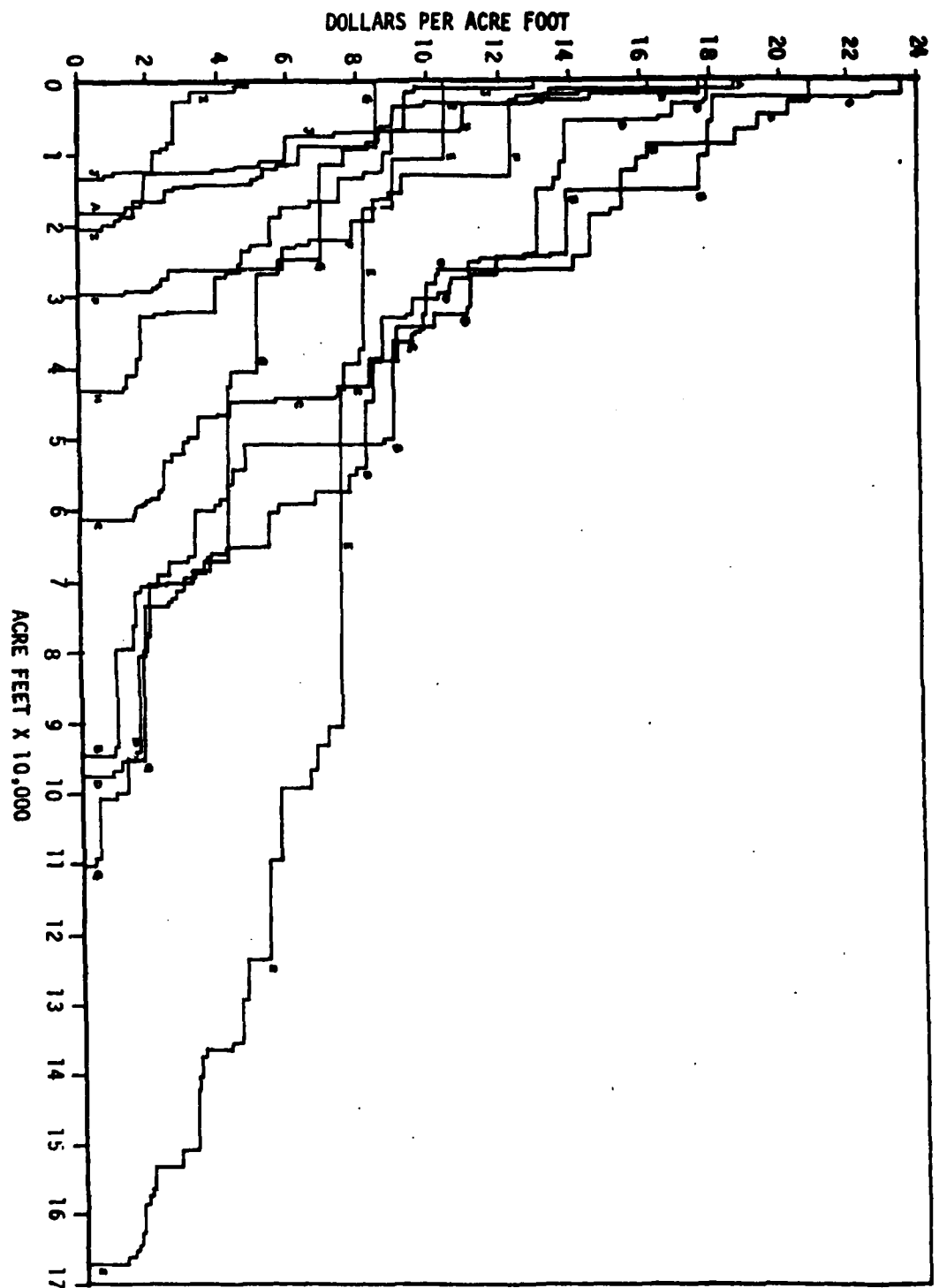


Figure 2. Illustrative linear programming model.

Figure 4. Demand for water for presently irrigated land.



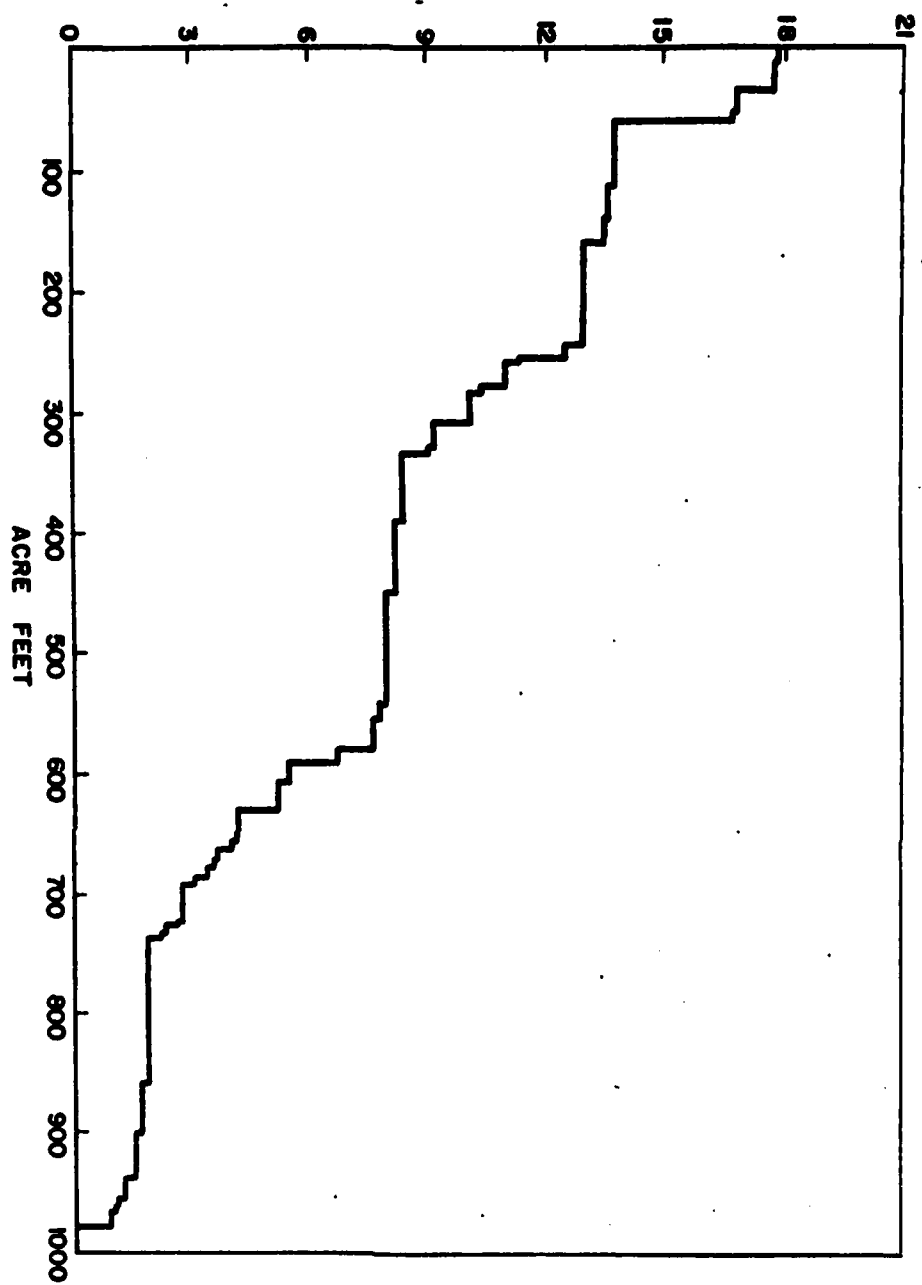


Figure 3. Demand for water in subsection 4.

obtained from the presently irrigated land through the use of more water and/or the transfer of water from lands with low productivity to higher quality land. There are, however, many cases of water waste. Present levels of use indicate low productivity for additional water. Putting water on new land involves added costs which drives the value of the water down further.

The model is not designed to adequately evaluate the economic feasibility of water importation projects, but those regions with the greatest potential for development are identified. The models indicate that, given the present cost and price structure, agriculture alone probably could not economically justify most water importation schemes at this time.

The study indicates that water consumed in agriculture has a maximum marginal productive value of about \$20 per acre foot. This is for a small amount of water on the best land and for the most profitable crops. Change of any of these factors reduces the marginal value productivity.

Compared to expected values of use in energy, the values for water in agriculture are quite low. We are just beginning on the estimates of the demand schedules for energy, but the evidence is accumulating. See Table 2. These results confirm and quantify the generally accepted conclusion that agriculture is the marginal or residual user of water. Further steps are now needed to estimate demand functions for other uses of water and to match these up with the supply (marginal cost) schedules. The findings of the study conclusively demonstrate the inadequacy of the "requirements" or fixed coefficient approach to water use estimates in planning. Much more effort is needed in many uses and in all geographic areas to provide an adequate planning base.

Table 2. Increase in costs of production for energy products. (J. Clair Batty, Unpublished Data, Utah State University, Logan, Utah, February 1975).

Water Use	Cost increases for a \$200 per acre ft increase in price of water
Coal Gasification	2%-8%
Coal Liquefaction	1%-6%
Coal Fired Electrical Gen.	1%-2%
Shale Oil	0.6%-1%
Coal Pipelines	2%-3%
Coal Mining	0%

THE REQUIREMENT FOR DISAGGREGATE FORECASTS^a

John J. Boland^b

INTRODUCTION

The forecasting of future water use levels is an activity of central importance to the water supply and wastewater disposal industry. The investment decisions which result from water use forecasts relate to both water and wastewater facilities. Although institutional arrangements vary, it should be obvious that water supply and wastewater disposal are, with rare exception, inextricably interwoven; effective planning must consider both functions simultaneously.

The water/wastewater industry is one of the largest and most capital-intensive in the U. S. economy. Data available from the U. S. Bureau of Census¹³, which exclude investor-owned utilities, indicate that 1977 expenditures for construction of new facilities (\$7.2 billion) accounted for 46 percent of all water/wastewater expenditures in that year (\$15.5 billion), exceeding even the electric utility industry (less than 40 percent). Since 1960, annual water/wastewater investment has grown at a real rate of 5.4 percent per year, that is, 5.4 percent *faster* than the rate of increase in construction costs. By comparison, capital expenditures in the private sector of the U. S. economy have grown at a real rate of less than 4 percent

^aPresented at the October 27-31, 1980, ASCE Fall Convention, held at Hollywood, Florida.

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during the same period.

Beyond these aggregate statistics, there are other characteristics of water and wastewater system investments which tend to focus attention on the planning process. Individual investments are typically large by comparison to the annual cash flow of the affected utility; facility life is long (often 50 years or more); and most projects involve substantial lead times (up to 20 years from commitment to completion).

The facilities planning task, then, is both difficult (planning is done at long range, with few opportunities for mid-course correction) and critical (individual decisions commit very large sums of money). Both water and wastewater facilities must be planned, programmed, and constructed to meet the demands imposed upon them by future water users. The level and pattern of future water use determines the type, size, and timing of the facilities to be provided. Forecasts of future water use should rest upon knowledge of the structure of urban water use; forecasting methods should reflect both that knowledge and the specific needs of the planning process.

The following sections review the role of water use forecasts, discussing current issues and applications. Various possible approaches to forecasting are described, and those which deal with disaggregations of total water use are contrasted to aggregate approaches. The advantages of disaggregate forecasting methods are discussed and illustrated with data from a Washington, D.C., area water utility. Finally, recommended forecasting techniques are outlined and conclusions offered.

WATER USE FORECASTS

The Role of Forecasts

A water use forecast is a conditional prediction of the level of water use at some future time. The forecast may refer to the average level of use in a given year (average day water use), or to any of a number of measures of variation in water use (summer season water use, maximum month water use, maximum day water use, peak hour water use, etc.). Forecasts may also address the average day contribution to sewer flow, sometimes approximated by a forecast of winter day water use.

Forecasts are conditional because they rest on a large number of assumptions, explicit or implicit, regarding future levels of water using activities, future relationships between levels of water use and of water using activities, future relative prices, etc. Any particular forecast is an estimate of expected future water use, *given that* all of the underlying assumptions prove correct. Accordingly, forecasting methods are as much concerned with finding the appropriate assumptions as with calculating expected water use given the assumptions.

The water use forecast, in turn, becomes one of the assumptions on which plans for water supply and wastewater disposal facilities are based. In most cases, facilities will be designed, sized, and programmed such that the present value cost of all required facilities is minimized, and future water demands are met as they are expected to occur. If actual water use turns out to be greater than forecast, however, the planned facilities may be inadequate. If actual water use is less than forecast, some facilities may have been constructed prematurely.

In either case, excess economic and environmental costs will be incurred. When facilities are inadequate, they will be pressed beyond economic loadings and/or service lives. Water supply deficits may also occur. Both results impose excess costs on water users. When facilities are constructed prematurely, users are required, at least for a time, to pay for unnecessary facilities. If those facilities cause environmental disruptions of any kind, the disruptions also occur sooner than necessary.

While short and medium range water use forecasts may be developed for other purposes, including operational and financial planning, the most familiar application is the preparation of forecasts for the long range future⁴. Ideally, such forecasts should balance, at the margin, the cost of over-estimating future water use with the expected cost of under-estimates³. Increasing the estimate of future water use should add facility and environmental costs which exceed the expected cost of shortages and of uneconomic use of existing facilities. Conversely, reducing the estimate of future water use should increase the expected cost of shortage by an amount which is larger than the facility cost thereby avoided. The "best" forecast method, then, is the one which permits the planner to achieve this balance most often.

Water supply planners often describe as "conservative" those forecasts which are consciously set above the most likely future water use level. It should be clear that what is conservative from the viewpoint of those responsible for providing facilities is not conservative from the viewpoint of those responsible for paying for them, or those who incur the environmental costs. "Conservatism" is not an appropriate criterion for forecasts; it implies a distinctly one-sided objective function. The criterion for

forecasting should be to minimize the sum of all expected costs associated with forecasting error: the goal is accuracy, not conservatism.

Current Issues

The task of forecasting future water use has certainly become even more critical and difficult in recent years. The increments of water supply capacity, and the additions to wastewater collection and disposal systems, that remain to be built are more expensive, often much more expensive, than their predecessors. There is greater awareness of the way in which such facilities as stream impoundments and wastewater discharges may preempt other uses of the natural environment, imposing costs on society. Further, as the economy becomes more complex, and as the performance of the water industry continues to be taken for granted, the dependence of users on uninterrupted water supply may be increasing, with commensurate increases in the expected cost of disruption, should it occur. These factors all increase the cost of forecast error, whether over-estimate or under-estimate, and intensify the requirement for accuracy.

At the same time, many signs point to fundamental changes in the structure of urban water use. Family sizes and life styles are changing: there are many more singles and childless couples, some young and some elderly, all contributing to steady increase in the fraction of housing units which are apartments, condominiums, and townhouses. Nationwide, single-family housing units, more than 77 percent of total housing stock in 1960, fell to 67 percent in 1977¹³. Employment patterns are changing, too, with the fraction of total nonagricultural employment in the low-water-use service industries rising from 62 percent in 1960 to almost 71 percent in 1977⁷.

Since 1970 the relative cost of water use has risen dramatically for many users, principally the result of basing wastewater charges on water use for the first time, or of dramatic increases in the level of existing wastewater charges. These higher costs have reinforced the rising concerns for the environmental effects of existing and planned water supply and wastewater disposal facilities, causing widespread re-assessment of long-standing habits of water use. Water conservation is advocated by environmental groups, by consumer groups, by manufacturers of water conservation devices, by water utilities, and by the federal government. President Carter, in announcing his Water Resources Policy Reform Message of June 6, 1978, stated:

Managing our vital water resources depends upon a balance of supply, demand, and wise use. Using water more efficiently is often cheaper and less damaging to the environment than developing additional supplies. While increases in supply will still be necessary, these reforms place emphasis on water conservation and make clear that this is now a national priority.

The extent to which our citizens will actually conserve water in response to these various incentives and exhortations is, as yet, unknown. Reducing water use clearly reduces the cost of supplying water and of removing wastewater, but it also imposes costs, usually directly on the water user. A recent study for the U. S. Army Corps of Engineers makes clear that the conservation of water is consistent with the conservation of all scarce resources only when the benefits (costs avoided) exceed the added costs¹. Data available at this time indicate that the desirability of individual conservation practices varies widely from one location to another, as a result

of differing supply costs, water use patterns, and population characteristics^{1, 12}.

Changes are occurring, therefore, in both the relative size of water using activities and the future intensity of water use by those activities. The shrinking proportion of single-family homes, resulting in less importance for lawn and garden irrigation, seems likely to reduce the sensitivity of water use to weather. Changing employment patterns may signal smaller shares of future water use attributable to industry, but possibly larger shares for commercial and institutional activity. Water conservation practices have the potential of reducing water use significantly, depending upon how beneficial they prove to be. All of these changes, some without recent precedent, compound the problem of forecasting water use.

Forecasting Approaches

The most widely used technique for water use forecasting is the "per capita requirements" approach. The demand for water is taken as a simple requirement, with all factors that might affect the use of water save one (population) assumed to be unchanging, or to change collectively exactly as they have done in the past. While such forecasts are easily prepared, and may prove useful in some applications, they have severe limitations for most purposes. They do not explicitly consider the impact of conservation measures and they do not reflect the effect of changes in such explanatory variables as housing mix (single family vs. apartment), residential lot size, industrial process change, commercial activity mix, income, water/wastewater rate structure, etc. Forecast water use values obtained by this method imply assumptions regarding future levels of explanatory variables

(other than population) which are not stated explicitly, and which may not be known, even to the person preparing the forecast.

Many analysts modify the per capita requirements approach to avoid some of the limitations noted above. A common variant separates industrial water use, employing the per capita method for residential and remaining non-residential uses. Industrial water use then may be forecast by any of several methods, usually requirements-oriented and based on analyses of historic water use by the specific industries affected. In other cases, the per capita water use figure obtained from past records may be modified to reflect changes expected to occur in the future: the detailed assumptions usually remain hidden, however.

Other forecasting approaches described in the literature fall into several categories. They may be aggregate approaches, where total urban, or total urban and industrial water use is forecast directly. They may be disaggregate approaches, forecasting various sectors such as single-family residential, multi-family residential, commercial, etc., separately. The aggregate forecast is obtained by summing the individual disaggregate forecasts. Some forecasting approaches are essentially requirements methods, where future water "needs" are obtained by bivariate or multivariate trend analysis, without including economic variables such as income and price. Other approaches utilize demand functions, which express a causal relationship between water use and the principal explanatory variables including, where appropriate, economic variables. Some such approaches have been applied in practical situations, others have not. Some utilize data which is ordinarily available, others may require special data collection efforts.

In designing a forecasting method, several broad choices must be made: the forecast may be on an aggregate or disaggregate basis, and it may utilize requirements or demand models. Aggregate forecasts consider urban water use, or urban less industrial water use, as a single entity, while disaggregate methods analyze and forecast individual sectors of water use (residential, commercial, institutional, industrial, for example) separately. Requirements models, as contrasted to demand models, exclude economic variables such as price and income. Beyond these initial choices, the actual explanatory variables must be chosen, the functional forms selected, etc.

Forecasting has been characterized as a process of explanation and prediction¹⁰. Forecasting models must be capable of explaining observed patterns of water use before they are relied upon for prediction. It is evident that recent trends in water use, and those anticipated for the near future, cannot be explained by methods that rely on historic trends in per capita water requirements. Rather, the use of disaggregate methods, preferably incorporating demand models, is strongly indicated.

Many combinations of characteristics are possible. The most advanced methods which seem to have been applied in actual planning efforts have been combinations of demand and requirement models, employed in a disaggregate framework. The particular types and forms of models are selected on the basis of data availability. Applications of such approaches are described in Boland (1971, 1978, and 1979) and Hittman Associates^{2, 3, 4, 11}. In some cases disaggregate requirements models have been used to good effect^{8, 9}. The forecasting method chosen depends upon data availability as well as the nature of the application.

DISAGGREGATE FORECASTS

The Structure of Urban Water Use

Water is not a single commodity used for a single purpose, like toothpaste or pencils. It is, instead, used in many different ways for many different purposes by many different types of user. Public water supply systems may provide water for purposes ranging from human consumption to fire suppression, from ornamental fountains to industrial processes. The total water use within an urban area is the aggregation of nearly countless individual uses, each use being governed by different considerations and subject to different influences. It should not be surprising, therefore, that the total quantity of water used varies widely among different communities and changes in widely different, sometimes unexpected ways over time.

In order to develop a practical capability for describing, estimating, and forecasting urban water use, it is necessary to introduce at least some generalization, since data and behavioral models are not available for all individual water uses. This is done by aggregating water uses into classes, or into user sectors (residential, commercial, etc.). Various levels of aggregation are possible ranging up to complete aggregation where only total urban water use is considered. Between the extremes of the unmanageable detail of individual water uses, and the relatively uninformative notion of total urban water use, numerous possibilities for describing and forecasting urban water use exist.

The level of aggregation selected for each forecasting application reflects at least four considerations. The most frequently cited obstacle

to disaggregate analysis is the lack of historic disaggregate water use data. Such data are obtained from customer billing records provided only that individual customer accounts are coded to indicate the class to which they belong. Where billing records are processed by computer, and data stored on magnetic tape or mass storage devices, disaggregate analysis of past water use is readily accomplished. If customer accounts have not been previously coded, the proper notations can be provided by meter readers as a part of the regular reading cycle.

Another criterion for selecting the level of disaggregation concerns the forecasting method that is to be employed. User classes should be as homogeneous as possible with respect to both explanatory variables and functional relationships if statistical or econometric models are to be satisfactorily employed. If reliable models of single family residential water use are available, it may be desirable to separate single family users from those who reside in apartments. Residential users without public sewer may be considered separately from those connected to sewers, commercial and institutional users may be separated into subclasses of establishments which use water for roughly the same purposes, etc.^{2, 11}.

Disaggregation should prevent significant trends in water use data from being concealed by aggregation. If residential water use per connection is falling because of changing housing mix and family size, while institutional use increases because of expansion of certain institutional functions, effective forecasting would deal with each of these trends separately, extrapolating or not as the evidence appears to warrant. Consideration of total water use only may suggest that no trend is present, as the two effects cancel one another.

Finally, disaggregation should facilitate explicit assumptions regarding the likely future effectiveness of water conservation measures. If the installation of water-saving plumbing fixtures is expected to reduce residential in-house water use by 10 percent, a separate forecast of this class of water use must be available so that the effect of a 10 percent reduction can be seen. If sprinkling water use is to be affected, sprinkling water use must be separately forecast. Just as forecasts of conservation effectiveness require class-by-class consideration, reports of experience with conservation measures in other communities are only helpful if they are presented on the same basis. The observation that a certain conservation measure reduces total water use by some percentage cannot be transferred to another community where the relative contributions of water user classes to the total are possibly different: disaggregate analysis is required.

Application of Disaggregate Analysis

The usefulness of disaggregate analysis can be illustrated by using data for a water/wastewater utility serving part of suburban Washington, D.C., the Washington Suburban Sanitary Commission (WSSC). This utility first coded customer accounts by user class in the early 1970's. The coding system was revised and the number of classes increased in 1973; further improvements were made in 1977. A detailed analysis of billed water use was performed as a part of a rate structure study in 1975⁵. A similar analysis was performed in 1980 incident to the development of a revenue forecasting model⁶. In the first case, data was obtained for the period September 1973 through August 1974; the second study used data for the period November 1978

through October 1979, almost exactly five years later.

During the five year period, a number of events occurred. WSSC continued its implementation, begun in 1971, of a comprehensive program encouraging water conservation by its customers. Water closets installed in new or substantially remodeled housing units are restricted to 3.5 gal (13 L) flush volumes, water conservation handbooks have been distributed, and continual reminders of the potential value of water conservation are provided via bill inserts, television announcements, press releases, etc.

Other changes involved rate-making policy. In 1975, WSSC charged \$1.08 per 1,000 gal (3 790 L) for water and wastewater service, regardless of the size or identity of the customer. Beginning in 1977, a 20 percent surcharge was applied to summer bills. In 1978, the Commission implemented a novel rate structure designed to encourage water conservation. An increasing-rate design is used, with combined water/wastewater rates which (in 1980) rise in 100 steps from \$1.26 per 1,000 gal (3 790 L) for customers using less than 20 gal (76 L) per day to \$3.11 per 1,000 gal (3 790 L) for customers using more than 1,000 gal (3 790 L) per day. This rate structure was expected to reduce both total water use and total contribution to sewer flow, thus easing pressure on existing facilities.

A casual examination of total water use figures for 1974 and 1979 may suggest that growth in water use was actually stemmed by the water conservation program and rate structure changes. Average day water use increased from 130.7 MGD (495 m³ per day) to 137.7 MGD (522 m³ per day), an annual rate of increase of only 1.0 percent, compared to the rate of growth of population served of approximately 2.1 percent per year. Table 1, column 4 shows water use per connection per day for both periods, indicating a decline

TABLE 1.
 AGGREGATE WATER USE PER CONNECTION,
 WASHINGTON SUBURBAN SANITARY COMMISSION, 1974-1979.^a
 In gal (L)/connection/day.

Year (1)	Non-Seasonal Water Use (2)	Seasonal Water Use (3)	Total Water Use (4)
Sep 1973 - Aug 1974	417 (1 580)	105 (398)	522 (1 978)
Nov 1978 - Oct 1979	449 (1 702)	8 (30)	457 (1 732)

^aData from Boland, et al., (1975) and Boland, Steiner and Wentworth (1980).

from 522 gal to 457 gal (1 978 L to 1 732 L). These figures, taken alone, suggest that the utility's programs have functioned as intended, and that the average level of water use has fallen. A further analysis will reveal some contradictions, however.

The first step is to remove seasonal water use from the total. Seasonal water use is defined as the excess over the winter (January, February, March) water use rate. The remainder, which is the annualized winter water use rate, is the nonseasonal water use shown in column 2 of Table 1. This water use is presumed to be unrelated to the various outside uses characteristic of warm weather (lawn and garden irrigation, air conditioning, car washing, etc.), and can be seen to actually *increase* between 1974 and 1979, by 32 gal (121 L) per connection per day. Seasonal water use, on the other hand, declined precipitously, reaching an average level of only 8 gal (30 L) per connection per day in 1979.

Several explanations can be offered for the drop in seasonal water use. 1979 was an unusually cool and wet year, greatly reducing the need to irrigate lawns and gardens, and to operate air conditioning. Still, the total seasonal moisture deficit was 7.26 inches (18.4 cm) which, when compared to 10.15 inches (25.8 cm) for the 1974 period, would suggest a much smaller reduction. The water conservation campaign and the rate structure may explain the remaining change, but this leaves unexplained the increase in non-seasonal use.

Further disaggregation provides more information on this point. Table 2 shows total water use per connection (column 4) for each of five user classes, with nonseasonal (column 2) and seasonal (column 3) data also provided for each class. Beginning with nonseasonal use (column 2), it can be

TABLE 2.

WATER USE PER CONNECTION BY SECTOR,
WASHINGTON SUBURBAN SANITARY COMMISSION, 1974 - 1979.^a
In gal (L)/connection/day.

Year (1)	Non-Seasonal Water Use (2)	Seasonal Water Use (3)	Total Water Use (4)
Single-Family Residential (incl. townhouses, mobile homes)			
Sep 1973 - Aug 1974	235 (891)	39 (148)	274 (1 038)
Nov 1978 - Oct 1979	221 (838)	3 (11)	224 (849)
Garden Apartments (less than four floors)			
Sep 1973 - Aug 1974	9 739 (36 911)	2 165 (8 205)	11 904 (45 116)
Nov 1978 - Oct 1979	11 903 (45 112)	-168 (-637)	11 735 (44 476)
High-Rise Apartments (more than three floors)			
Sep 1973 - Aug 1974	21 690 (82 205)	2 836 (10 748)	24 526 (92 954)
Nov 1978 - Oct 1979	25 804 (97 797)	88 (334)	25 892 (98 131)
Commercial, Industrial			
Sep 1973 - Aug 1974	1 633 (6 189)	512 (1 940)	2 145 (8 130)
Nov 1978 - Oct 1979	1 436 (5 442)	108 (409)	1 544 (5 852)
Institutional (federal, state, local government; schools, etc.)			
Sep 1973 - Aug 1974	19 784 (74 981)	3 418 (12 954)	23 202 (87 936)
Nov 1978 - Oct 1979	8 082 (30 631)	924 (3 502)	9 006 (34 133)

^aData from Boland, et al., (1975), and Boland, Steiner, and Wentworth (1980).

seen that Single-Family Residential, Commercial, Industrial, and Institutional users all reduced nonseasonal water use in the period. In the case of the nonresidential categories, it is possible that changes in the size of the average establishment may have occurred (trends to smaller retail establishments, for example), but this alone is unlikely to explain the large differences shown.

The user classes which did not reduce nonseasonal water use — which, in fact, increased use by an amount more than sufficient to cancel the reductions in other classes — are the two groups of apartment users. It should be noted that, while apartment occupants are exposed to the conservation campaign and must comply with the plumbing code calling for water-saving appliances, they do not pay their own water bills — the building owner pays the water bill for the entire project. The effect of the rate structure, therefore, is expected to be nil as regards nonseasonal use by apartment occupants.

The disaggregate record of seasonal water use shows a different picture: all user classes made very significant reductions in seasonal water use. If the explanations noted above are accepted for the customer classes other than apartments, it need only be pointed out that apartment building owners, who are expected to respond to price incentives, typically control the outside, or seasonal water use in an apartment project. This may explain the consistent changes in seasonal, as opposed to nonseasonal water use.

Armed with these new insights into the effect of rate-making policy and water conservation on water use, forecasts can be prepared which explicitly consider the response of single-family residential, commercial,

institutional, and industrial customers to price incentives; the response of seasonal water use to both price incentives and weather; and the lack of response of apartment use to economic incentive. Further, separate consideration of single-family homes and apartments allows expected changes in the housing mix to be incorporated into the forecast. Since apartment units average only 80 gal (303 L) per apartment unit per day (nonseasonal), compared to at least 220 gal (834 L) per housing unit per day for single family residences, changes in the relative proportion of apartments are likely to change total water use noticeably⁶. The effectiveness of water conservation measures which apply to specific groups of water users can be conveniently described and forecast in this framework as well, facilitating investigation of the sensitivity of total water use to possible conservation actions.

CONCLUSIONS

The requirements placed on water use forecasts have become much more severe in an era of increasing water supply and wastewater disposal cost. Furthermore, the environment in which forecasts must be prepared has become more complex for many reasons: recent changes in long-established trends, sharp increases in the real level of water/wastewater user charges, the need to consider future implementation of water conservation measures, etc.

In order to adequately describe changes now taking place in the structure of urban water use, and to provide forecasts of future water use which incorporate those changes, disaggregate forecasting approaches are required. Water use must be disaggregated into a sufficient number of user classes

so that underlying, often countervailing, trends become visible, so that effective forecasting models can be used, and so that the effects of proposed conservation measures can be expressed separately for each class of water use. The primary data source for disaggregate analysis of current water use is the customer billing records of local water utilities.

A disaggregate analysis of water use data from a Washington, D.C., area water/wastewater utility shows that an apparent reduction in average day water use in response to a new pricing policy was actually confined to certain classes of customer. Those that do not pay their own water bill (apartment users) actually increased consumption sufficiently to increase overall nonseasonal rates of use. A sharp drop in seasonal use as a partial consequence of a cool, wet summer was responsible for lower total use. Forecasts of future water use for this utility, had they been based on aggregate data, would almost certainly have seriously underestimated future use levels. A disaggregate forecast can reflect all of the observed trends, including changes in the relative sizes of user classes, providing much more reliable predictions of future conditions.

REFERENCES

- ¹Baumann, D.D., Boland, J.J., Sims, J.H., Kranzer, B., and Carver, P.H., "The Role of Conservation in Water Supply Planning," *IWR Contract Report 79-2*, Institute for Water Resources, U. S. Army Corps of Engineers, Fort Belvoir, VA., April, 1979.
- ²Boland, J.J., "The Micro-Approach - Computerized Models for Municipal Water Requirements," *Treatise on Urban Water Systems*, Albertson, et al., eds., Colorado State University, Fort Collins, CO., 1971, pp. 295-316.
- ³_____, "Forecasting the Demand for Urban Water," *Municipal Water Systems*, Holtz and Sebastian, eds., Indiana University Press, Bloomington, IN., 1978, pp. 91-114.
- ⁴_____, "The Requirement for Urban Water - A Disaggregate Analysis", *1979 Annual Conference Proceedings*, Vol. 1, Am. Water Works Assoc., San Francisco, CA., June 24-29, 1979, pp. 51-66.
- ⁵_____, Hanke, S.H., Church, R.L., and Carver, P.H., "An Examination of Alternate Rate-Making Policies for the Washington Suburban Sanitary Commission," Washington Suburban Sanitary Comm., Hyattsville, MD., 1975.
- ⁶_____, Steiner, R.C., and Wentworth, R.W., "A Short Term Revenue Forecasting Model for the WSSC," Washington Suburban Sanitary Comm., Hyattsville, MD., Oct., 1980.
- ⁷Bureau of Labor Statistics, *Handbook of Labor Statistics: 1978*, Bulletin 2000, U. S. Dept. of Labor, Washington, D.C., 1979, p. 134.
- ⁸Carver, P.H., "Price as a Water Utility Management Tool Under Stochastic Conditions," thesis presented to The Johns Hopkins University, Baltimore, MD., in 1978, in partial fulfillment of the requirements for the degree of Doctor of Philosophy.
- ⁹Ecological Analysts, Inc., "Water Supply Study for Montgomery and Prince Georges Counties, Maryland," for Bi-County Water Supply Task Force and Washington Suburban Sanitary Commission, Hyattsville, MD., 1977.
- ¹⁰Gallagher, D.R., Boland, J.J., LePlastrier, B.J., and Howell, D.T., "Methods for Forecasting Urban Water Demands," Australian Water Resources Council, Dept. of National Development, Canberra, A.C.T., Australia, 1980.

REFERENCES (Continued)

¹¹Hittman Associates, Inc., "Forecasting Municipal Water Requirements: The MAIN II System," Vol. I, Columbia, MD., 1969.

¹²Planning and Management Consultants, Ltd., "An Annotated Bibliography on Water Conservation," *IWR Contract Report 79-3*, Institute for Water Resources, U. S. Army Corps of Engineers, Fort Belvoir, VA., Apr., 1979.

¹³U.S. Bureau of the Census, *Statistical Abstract of the United States: 1979*, 100th ed., U. S. Govt. Printing Office, Washington, D.C., 1979, pp. 288, 483, 560, 773, 782.

CHANGING WATER-USE IN INDUSTRY

**A Paper Presented at a Conference on
Water Supply and Water Quality Planning**

Atlanta, Georgia

December 10-12, 1975

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Supply vs. Demand: An Irony

For the past two decades national economic policies have focused primarily on the maintenance and expansion of aggregate demand. Concerted public policies to insure the sustained growth of aggregate supply were virtually nonexistent.

Even in the private sector, our recent past has emphasized demand manipulation. One need only observe student enthusiasm for marketing courses at business schools to see the importance business managers place on demand control.

While demand was the focus of the rest of the economy, however, water resource planners were focusing their efforts on water supply and water quality. Studies of water demand were often limited to the residential and agricultural sectors. The demand for water in industry was taken essentially as a "given."

Today, planners and policy makers at the national level recognize that pressures on raw materials, financial capital and managerial resources all dictate a shift in emphasis to supply considerations: Will deficient energy supplies stymie efforts to reinvigorate the economy? Will capital equipment bottlenecks bankrupt industries attempting to comply with the new production requirements mandated by EPA and OSHA? Will a capital gap prevent the U.S. economy from achieving and sustaining once again high levels of economic growth?

In the private business sector as well, more managerial attention is being devoted to the control of operations. At Harvard, enrollment in courses in operations management has been increasing rapidly as students recognize that today operations management can prove a "fast track" to the top -- a possibility which seemed non-existent to most MBA students only five years ago.

It is perhaps ironical therefore, that economists and business leaders have been turning their attention from demand to supply management, the strength of water resource analysts, at the very same time that these water analysts have been shifting their attention to issues of demand analysis.

Water resources research is not retrogressing, however. The reasons for this shifting emphasis are clear and justified. First, constraints on financial resources to fund water supply projects are real and tightening. Increasingly, the public requires more systematic analytical justification for large-scale capital investments. Second, and perhaps more importantly, the cost of water resources to industry has skyrocketed in recent years. New industrial sites which provide access to high volumes of quality water are limited in number; the costs of withdrawing, utilizing and discharging water have grown significantly.

Consequently, changes in demand for water resources, which might justifiably have been assigned a lower research priority in the past are now of crucial importance in determining the economic viability of any planned expansion of water supplies.

The Empirical Evidence

Obviously, the industrial demand for water is not something which has suddenly changed after remaining stagnant for many years. An examination of the aggregate statistics on industrial water use from the Census clearly shows that changing patterns of industrial water use have a long history. Exhibits 1 and 2 illustrate these trends.

Exhibit 1 (Panel A) shows the ratio of intake water per unit of value added over time. This downward sloping trend can be compared with the virtually unchanged relationship between gross water applied and value added (Exhibit 1, Panel B). These changes have been made possible by the secular increases in the rates of water recycling. These trends are summarized in Exhibit 2 where reuse factors are plotted over time for the major users of water in the manufacturing sector of the economy.

The Nature of Demand

These aggregate statistics, although they can illustrate trends in water use and document the fact that these trends are common to several industries, cannot identify the major sources of these changes.

Factor Substitution: The simplest, and most obvious, source of changing water use in industry is input factor substitution. As the cost of water resources increases relative to other factor inputs, management substitutes these lower cost factors for water in production processes.

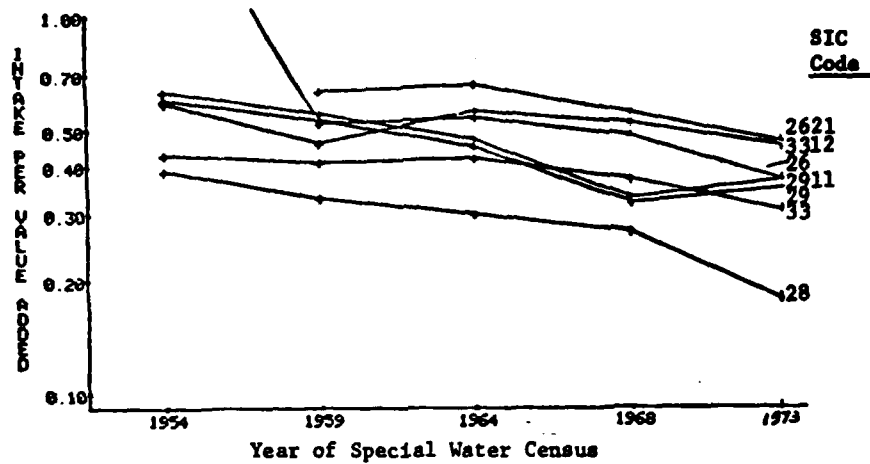
Exhibit 1

Intake and Gross Water Per Unit of Value Added
For Selected Manufacturing Industries

National Averages 1954-1973

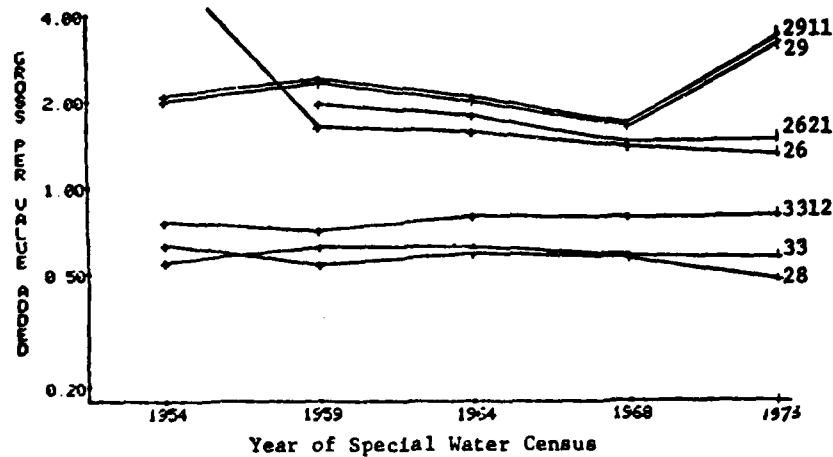
Panel A

Changes Over Time in the Volume of Intake Water Per Unit
of Value Added



Panel B

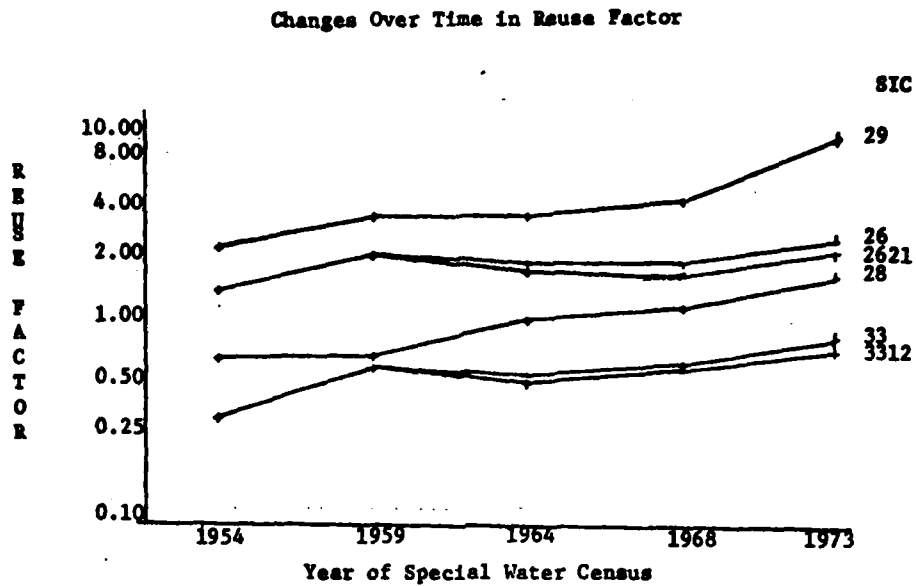
Changes Over Time in the Volume of Gross Water Per Unit
of Value Added



Source: Blanchard and Hill, An Extension of "Changing Water Use in Selected Manufacturing Industries" Including 1973 Data, September 1975.

Exhibit 2

Reuse Factor for Selected Manufacturing Industries
National Averages 1954-1973



Source: Blanchard and Hill, An Extension of "Changing Water Use in Selected Manufacturing Industries" Including 1973 Data, September 1975.

Since the cost of waste water discharge has grown disproportionately faster than other production costs in recent years, industry has tended to economize on waste water discharge by limiting water intake and increasing the intensity of water recirculation.

In our 1973 study for the Corps, we concluded that the opportunities for reductions in water use in manufacturing by factor substitution were apparently widespread. We based this conclusion not on an engineering analysis of the technical possibilities for reduced water use but rather on an economic analysis of the price elasticity of demand for water in selected manufacturing industries.

Our results are summarized in Exhibit 3. In the table, the demand for intake water (per unit output) with respect to the price of gross water is typically inelastic: a given percentage increase in the price of gross water results in a smaller percentage decrease in the intake of water. The demand for intake water is typically elastic with respect to the cost of intake (including the cost of discharge). Hence, an increase in the price of intake water tends to reduce the total bill for intake water.

The last set of demand elasticities shown in Exhibit 3 summarizes the relationship between intake water demand and the cost of recycling water. As recycling costs rise, industry economizes on recycled water by increasing withdrawals of intake water.

Exhibit 3

Estimates of Price Elasticities of Water Demand

price elasticity of intake water per unit of value added with respect to the price of	Least-squares estimate							
	ordinary				two-stage			
	Paper	Chemicals	Petroleum	Steel	Paper	Chemicals	Petroleum	Steel
Gross Water	-.4	-.7	-.9	-1.1	-.3	-.9	-.5	-.7
Intake Water	-1.4	-.7	-1.4	-1.6	-1.6	-.6	-1.5	-1.2
Recycled Water	.9	-.0	.5	.5	1.3	-.3	1.0	.6

Source: Leone, Ginn, Lin, Changing Water Use in Selected Manufacturing Industries, a report of National Bureau of Economic Research to the Institute for Water Resources, U. S. Army Corps of Engineers, 1973.

Technological Change: Over time, technological change permits the changes in water use summarized in Exhibits 1 to 3 to take place. Often these technological innovations are themselves the result of managerial efforts to reduce the cost of utilizing water resources. The introduction of waste water recycling systems are often justified on this ground, for example.

Much of the technological innovation which has the result of conserving on water resources is motivated by a desire to economize on the use of other resources, however. For example, many by-product recovery systems are justified by the value of the resources recovered. Often the result is clean water, suitable for recycling.

Changes in Inputs: There are often forces independent of technological change which can materially alter water resource demands. In many basic industries, for example, the degradation of raw material inputs over time has increased the intensity and complexity of processing required to produce a given output. Frequently, this more intensive processing requires the application of more water resources. As lower grade ore sources displace exhausted high grade ore supplies, for example, it can take more water to produce a ton of steel. Frequently, however, the site where this water resource is demanded can shift. Consider, for example, the demands for water resources to produce oil from shale.

Changes in Product Mix: With the passage of time, the characteristics of the products produced with water inputs change. In the paper industry, for example, competition from substitute materials has reduced the number of low volume specialty papers which the industry need produce. This has, in turn, reduced the industry's demand for water resources.

Again, using the paper industry as an example, the costs of using water resources are increasing so significantly that changes in product mix may well result. We have estimated, for example, that a 10% reduction in the brightness of bleached kraft paper could reduce total production costs by about 1% and decrease the volume of input water by about at least one-sixth.

In the petroleum industry, we have projected costs of \$100 million annually to treat the higher volumes of waste water generated by the more complex refinery processes necessary to produce the unleaded gasoline required for compliance with clean air standards. This major increase in water costs, induced by the change in the refiner's output mix, is likely to lead to further substantial changes in water intake and recycling in the refining industry.

Prospects for the Future

As we have seen, major changes in industrial water use have been occurring in recent years. Most of these changes are consistent with the responses to the rising cost of water resources that economic analyses would predict.

DROUGHT MANAGEMENT

EVALUATING ECONOMIC RISKS IN
WATER SUPPLY PLANNING

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U.S. ARMY CORPS OF ENGINEERS
INSTITUTE FOR WATER RESOURCES

Training Course on
Economic, Social and Institutional Aspects
of Water Supply Planning
Albuquerque, New Mexico
March 20, 1978

General.

This presentation discusses and reflects upon a study done for IWR in 1972. The IWR study reviewed and analyzed the drought of 1966 in York, PA. This led to a methodology for risk evaluation. The 1966 situation in York was similar in many respects to the drought in 1977 in northern Virginia. Authorities in both cases reacted similarly.

Drought planning requires a definition for shortage. An operational definition, that permits economic analysis is

"any time the water purveyor chooses, or is forced into, a position where he cannot supply the total demand for water in the system."

A definition for risk is also necessary. The definition in an economic context is:

"the present worth of the time stream of expected annual losses."

The perspective on losses is critical. The IWR study perspective is the region as a whole. Economic leakages across the regional boundary constitute the losses. These losses are caused by shortage and are categorized as

1. lost taxes and payroll to industry that is held by outside ownership
2. domestic consumer surplus
3. loss of profits by industry that is held by local ownership
4. stock losses to the commercial sector, and
5. payments for imported water.

Another perspective is that of the water purveyor, himself. His losses are:

1. lost revenue, and
2. added expense for imports.

Other perspectives are possible. Whatever perspective is taken, the losses are estimated for various drought severities. Each severity has a probability. The risk is the weighted sum of the loss times its appropriate probability.

Drought mitigation is provided by additional storage or reserve capacity. Evaluation should contrast reserves with risks. Mitigation may also be accomplished through demand contraction. In the IWR methodology this is considered a short term response and is included in the evaluation of losses.

Risk evaluation is usually conducted within a framework of minimum cost facilities to meet demands. Risks then are a short term attribute of the installed capacity. As such, the total cost is the cost of the facilities plus the associated risk. Minimization of cost plus risk, with installed capacity as the decision variable, is the objective of the IWR methodology.

The yearly risk for each capacity will increase with time, if demand increases, other things being equal. This risk timestream is handled through the usage of present worth calculations.

Specifics.

The specifics of this presentation are shown in seven figures.

1. Fig. 1. This figure illustrates the risk vs storage response of a water supply system subject to drought.
2. Fig. 2. A regional view of the losses are shown in this figure. Estimation of the various losses is tedious and is discussed in the IWR study.
3. Fig. 3. A purveyor's view of the losses and actual responses to drought in Fairfax Co., VA and York, PA are shown in this figure. The two losses are lost revenue and costs of emergency supplies. Planners may wish to take this view, since system design expansion is pursued by purveyors, as a rule. Note that in both cases the "additional expense" option was not acted upon until the reserves dipped to about 1 months supply.
4. Fig. 4. This figure shows the management responses as a function of the reserve capacity for Fairfax Co., VA and York, PA. Implied by this figure is the existence of a set of rules that govern response. It is convenient to characterize these as "reservoir rules" since the actions are keyed to the state of the reservoir.
5. Fig. 5. This figure shows the demand relationships and highlights the difference between regional and purveyor perspectives.
6. Fig. 6. A ranking of sensitive factors for the York, PA case study, with a regional perspective is shown. The three most important factors are: per capita demand, the estimation of drought inflows and the interest rate.
7. Fig. 7. This figure shows the steps that could constitute a drought study. The IWR study used a simulation model, but it appears that this degree

of sophistication may not be necessary. If the water purveyors view is taken, the calculations could be greatly simplified. The various steps in Fig. 7 give a good guide to what should go into the analysis.

Summary.

This presentation highlighted a risk methodology for water supply planning. Common response characteristics of management to drought are shown for two case studies. The analysis perspective, regional or purveyor or otherwise, is shown to be important.

Reference.

Young, G.K., Taylor, R.S., and Hanks, J.J., "A Methodology for Assessing Economic Risk of Water Supply Shortages," IWR Report 72-6, May 1972.

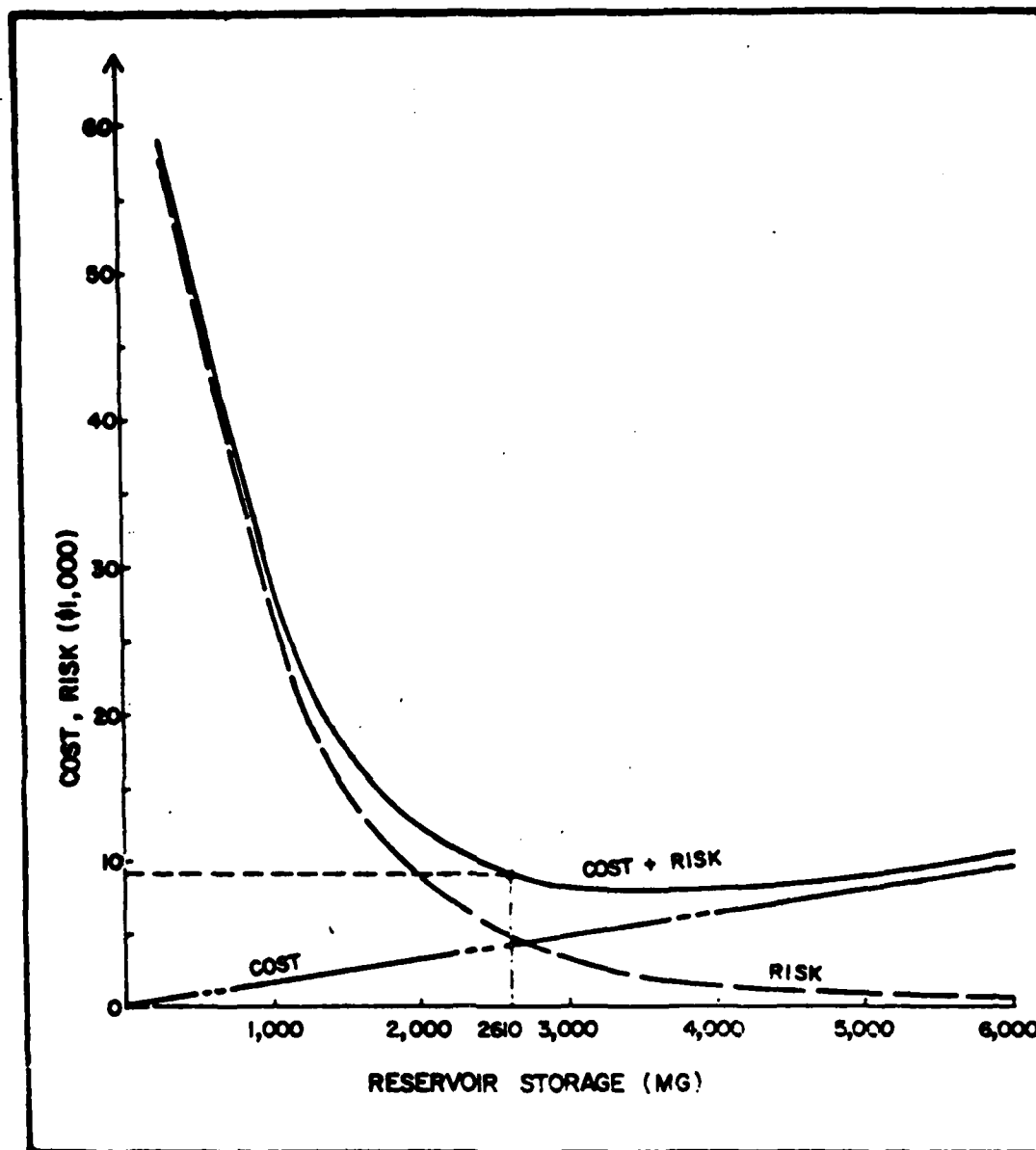
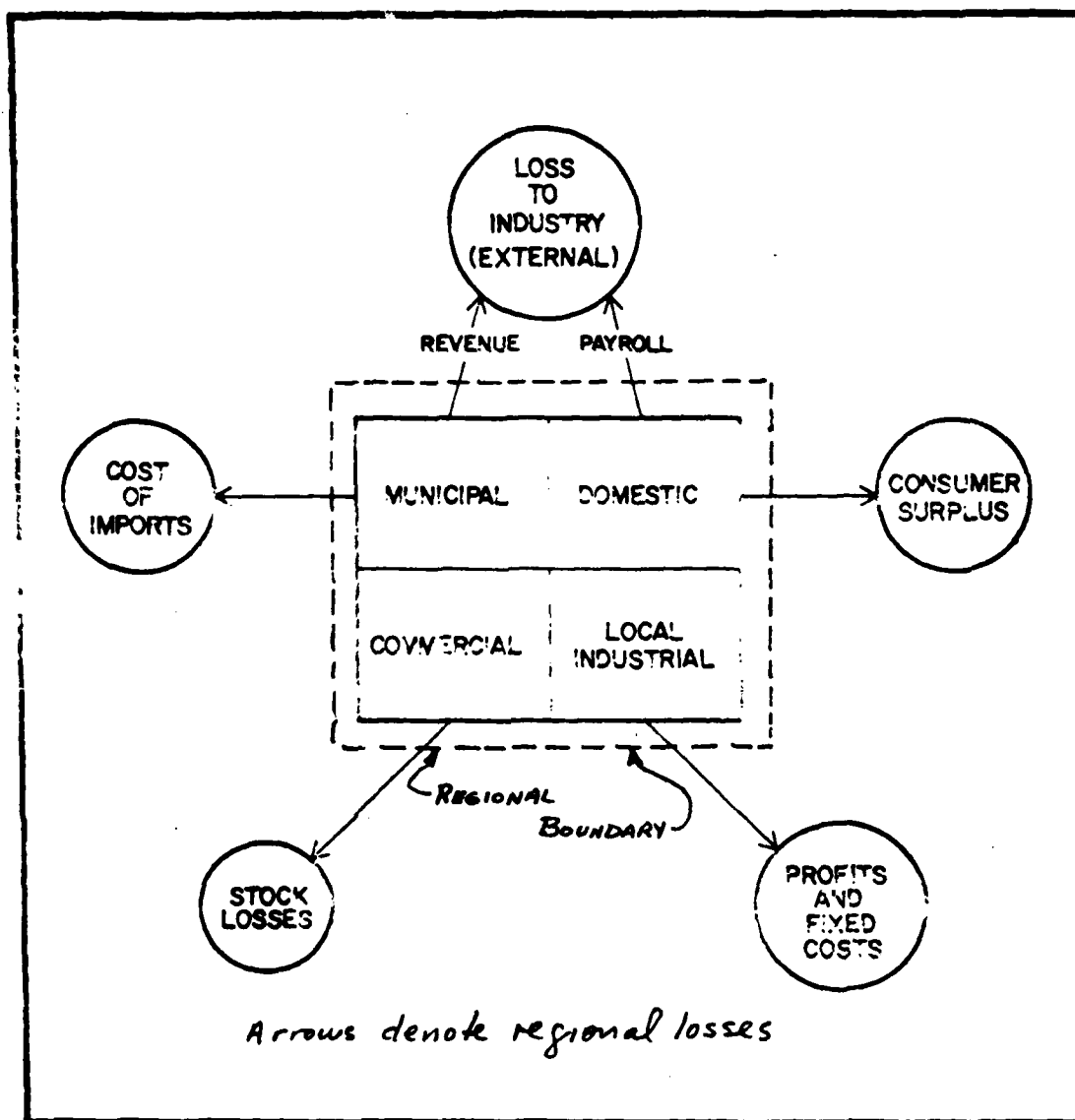


Fig 1
RISK VS. STORAGE



ECONOMIC RESPONSES-REGIONAL VIEW

Fig. 2

SITUATION		POSTURE	CONSEQUENCE (MUNICIPAL VIEWPOINT)
DAYS OF RESERVE			
FX. CO., VA.	YORK, PA.		
140	48	• NORMAL	
62	38	• RESTRICTIONS to contract demand A. VOLUNTARY B. MANDATORY	• LOST REVENUE
33	35	• ADD SOURCES	• ADDITIONAL EXPENSE

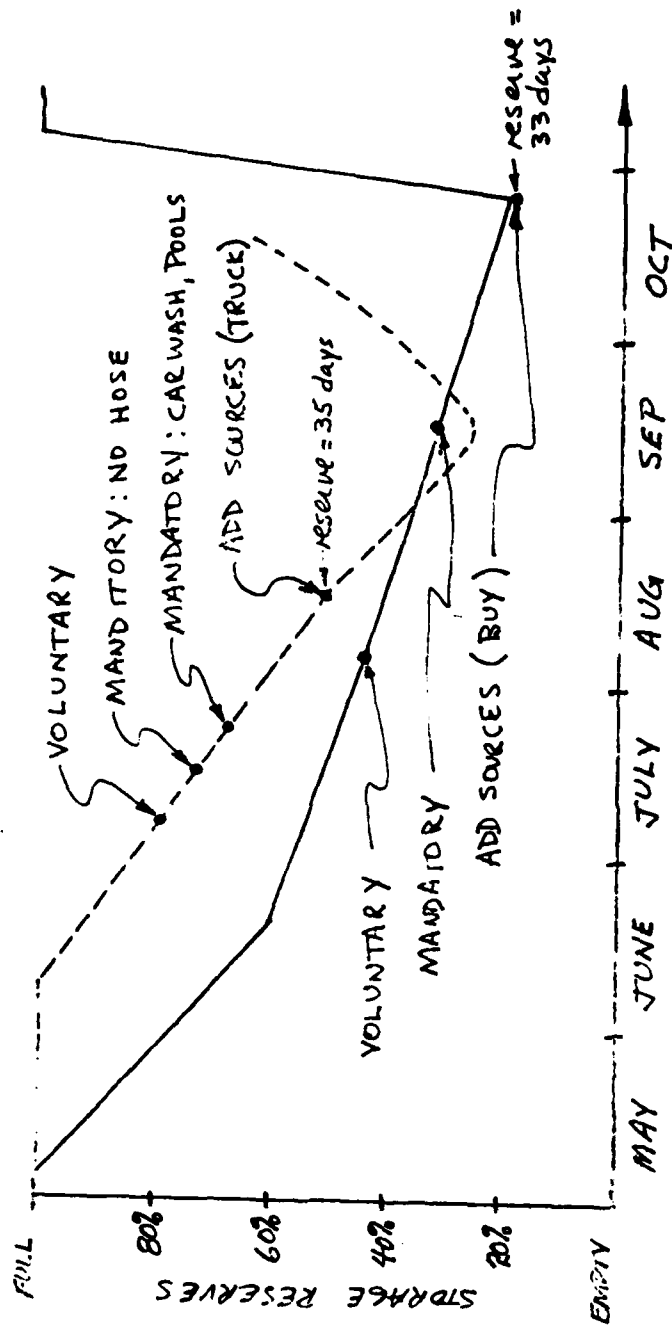
ECONOMIC RESPONSES —
PURVEYORS' VIEW

Fig. 3

AMT of RESERVE

48 DAYS ——— YORK, PA, 1966, POP 100K, STOR 1.2 BG
 140 DAYS ——— FX.CO, VA, 1977, POP 600K, STOR 9.8 BG

ABNORMAL FREEZING



YORK DEMAND CONTRACTION 25 MGD → 17 MGD (32%)
 FX.CO. DEMAND CONTRACTION 70 MGD → 59 MGD (16%)

Fig. 4
 MANAGEMENT RESPONSES

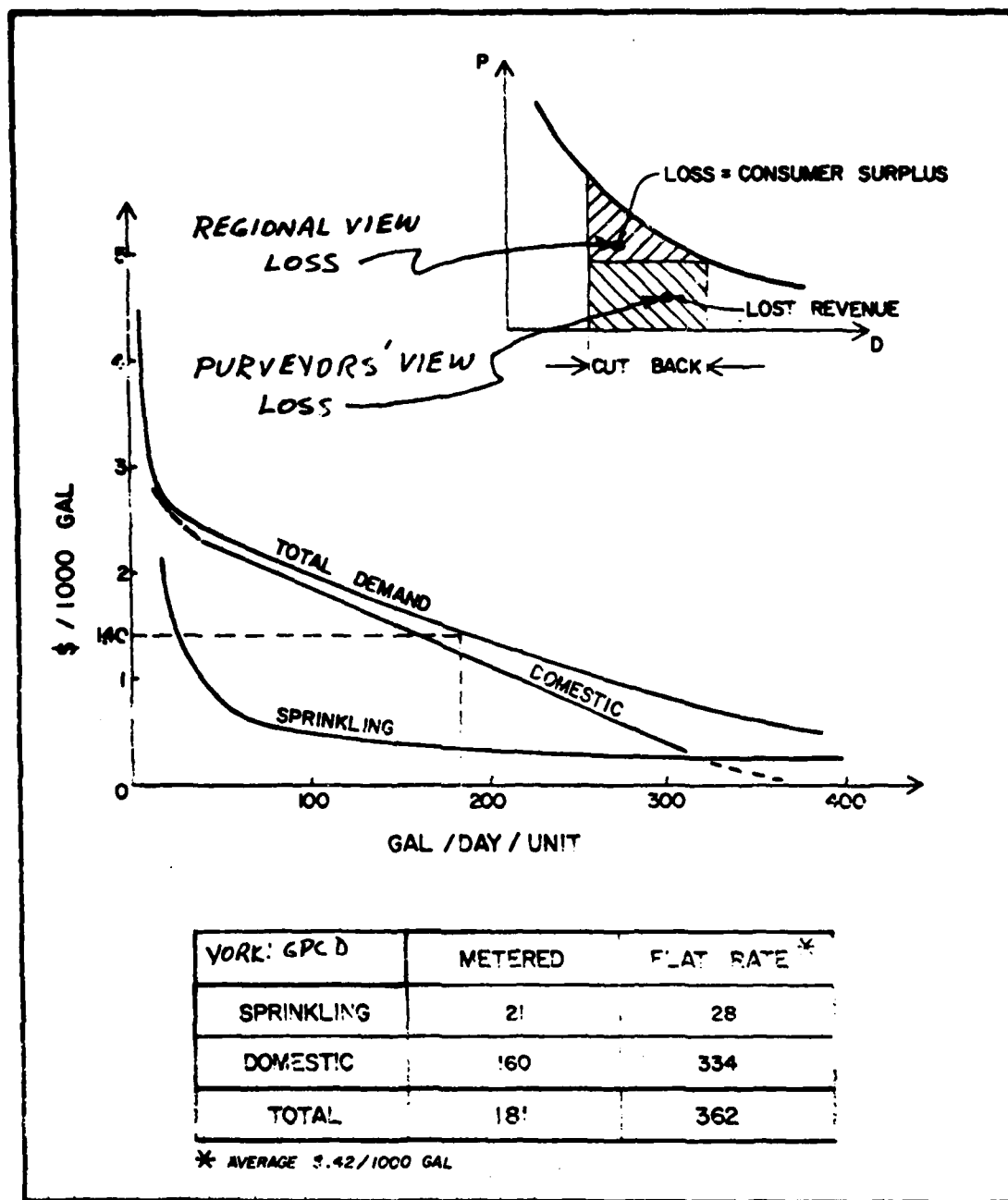


Fig. 5
DOMESTIC DEMANDS

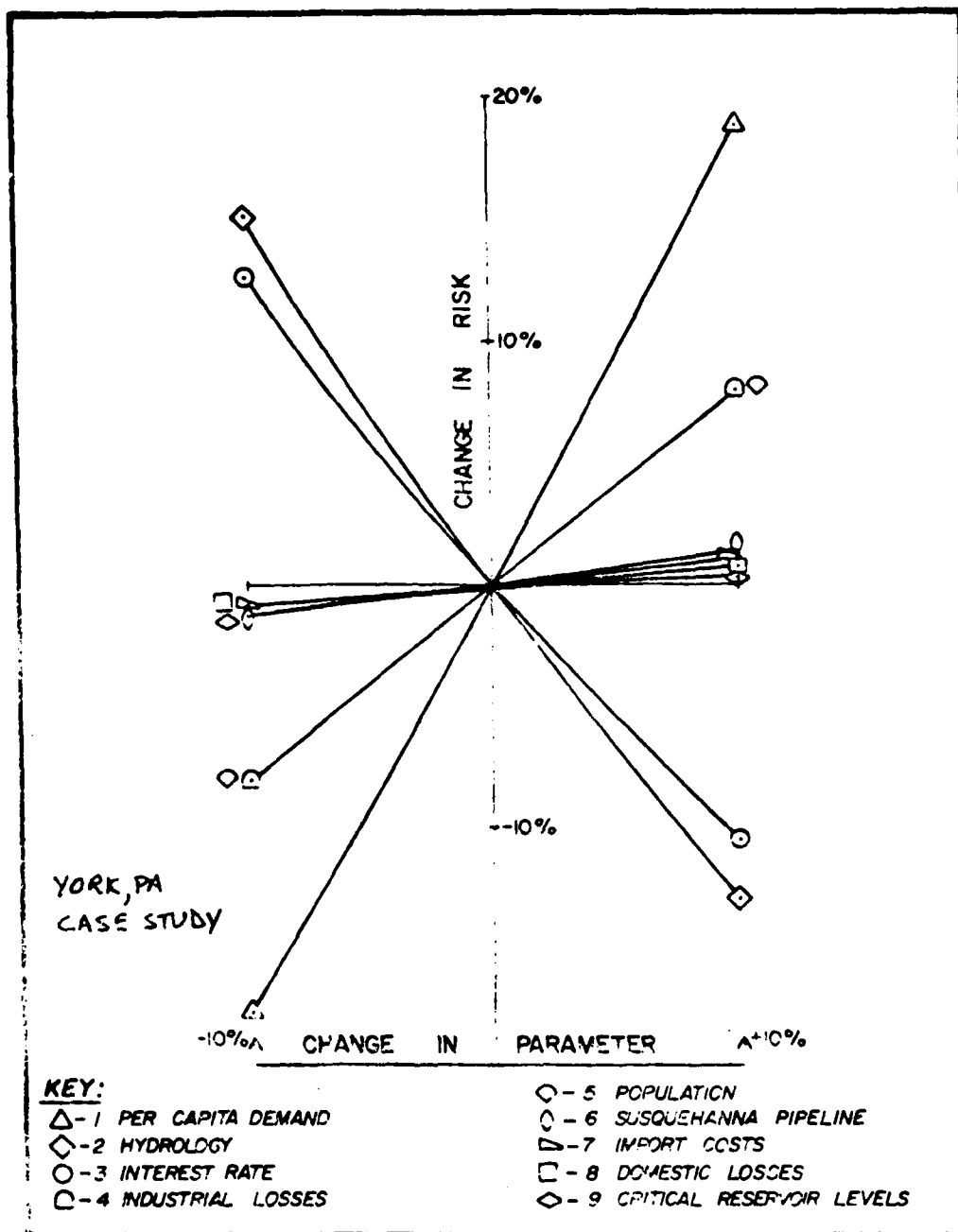


Fig 6
SENSITIVE FACTORS - REGIONAL VIEW

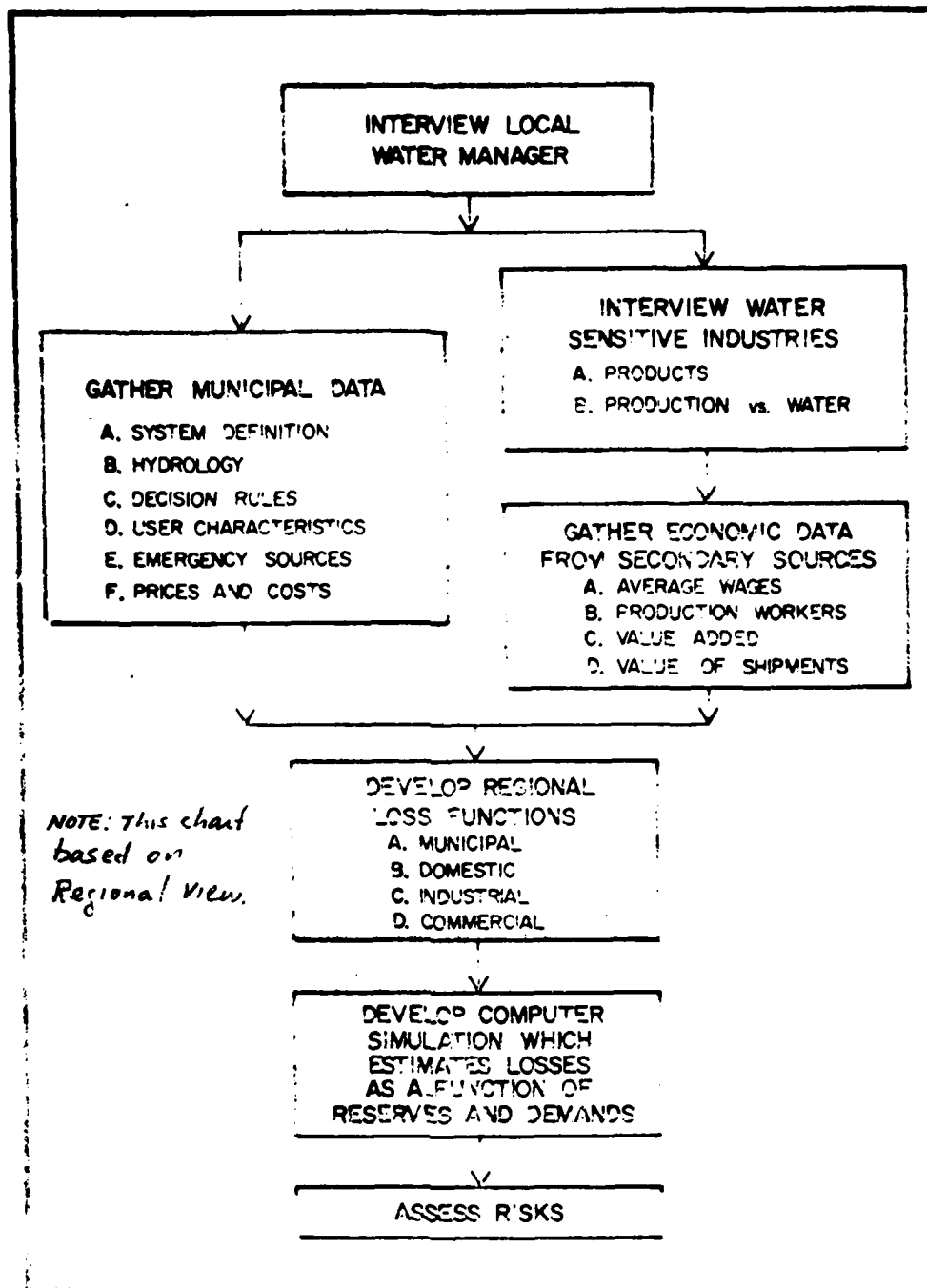


Fig. 7
STEPS FOR RISK STUDY

Community Response and Change in
Residential Water Use to Conservation
and Rationing Measures: A Case
Study -- Marin Municipal Water District ^{1/}
by
Frank H. Bollman and Melinda A. Merritt ^{2/}
Department of Water Resources
The Resources Agency
State of California

The communities of Marin County and its economy are still experiencing one of the most prolonged and severe droughts in its history.

The drought continues unabated. To offset the effects of the water shortage and to conserve limited supplies, the two major water districts, the many smaller water suppliers, county, state, and federal agencies, city administrations, school districts, businesses, farmers, and nurserymen, and not least residents, have employed myriad and diverse ways to cope. Consequently, the county is an interesting laboratory for studying the many institutional changes that have occurred in water management within the last two years in response to the drought.

This coastal county, largely dependent prior to the drought for its water supplies on internal sources, is typical in many respects of other coastal counties. It possesses approximately the same urban-rural mix as other coastal counties north and south of it. Since water districts in Marin County have been

^{1/}Paper presented at the Fall Conference of the California-Nevada Section of the American Water Works Association; San Jose Hyatt House, San Jose, California; October 19-21, 1977.

^{2/}The authors are respectively, Consultant (Natural Resources Economics) and Staff Services Analyst in the Division of Planning.

We wish to acknowledge the assistance of Janelle L. Hambright, Susan Bakker, Tom A. Gorin, Graduate Student Assistants with the Department of Water Resources; also the excellent cooperation and assistance from Marin Municipal Water District management and staff.

on the forefront of coping with the drought, the lessons learned should have valuable insights for and transferability to other water districts which are now facing the problems of acute water shortage which have been Marin's unfortunate legacy for some two years.

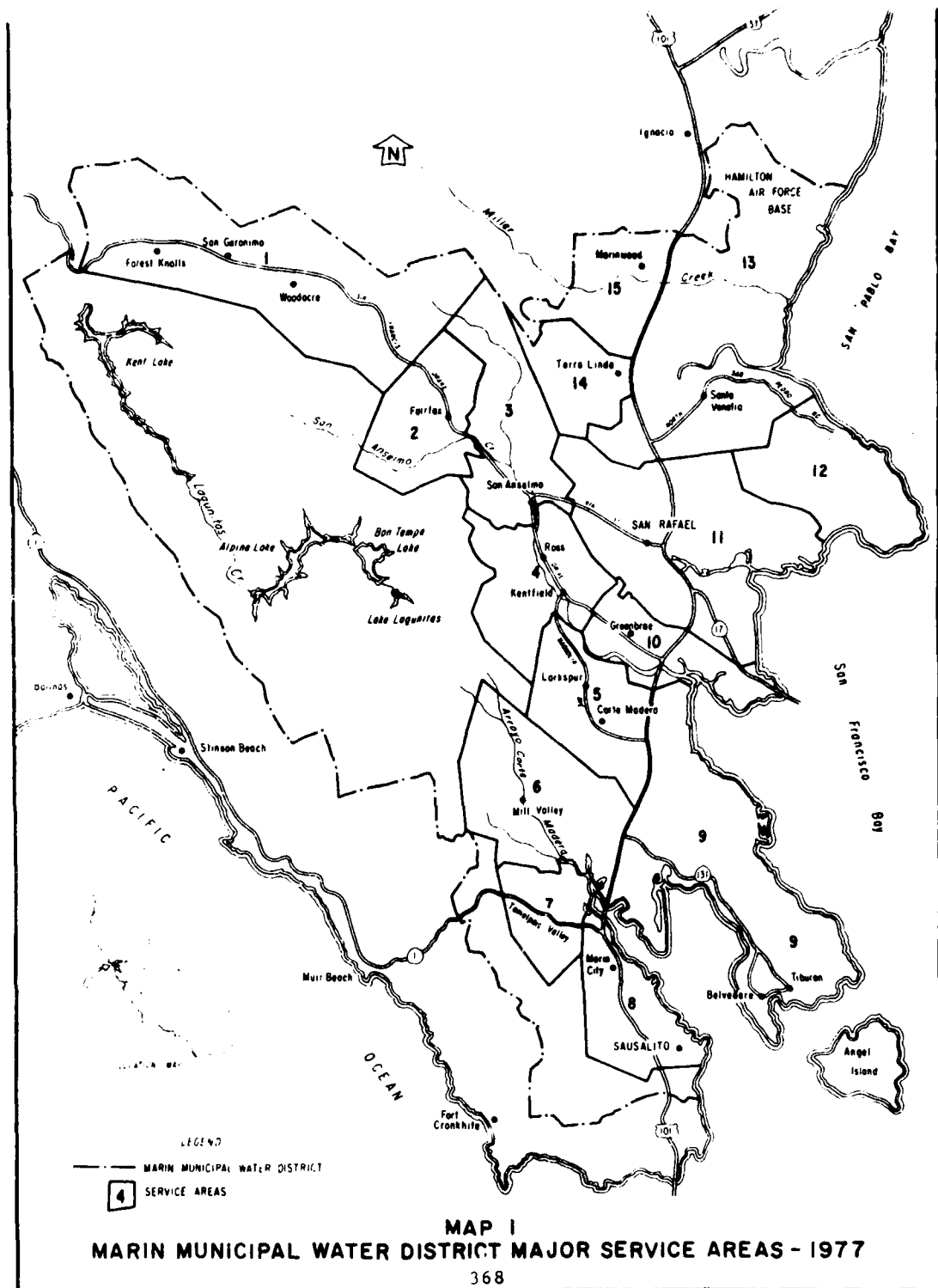
This paper does not attempt to deal comprehensively with all aspects of the effects and changes brought about by water rationing ordinances and conservation measures for all segments of the community in Marin or for all water districts. This paper simply reports some preliminary findings for a selected 1,000 single home residents served by Marin Municipal Water District (MMWD).

It consequently reports on only a small part of the information collected by the Department of Water Resources in Marin County. The more comprehensive mail questionnaire and personal interview survey conducted by the Department seeks to assess the changes in water use brought about by the water shortage and public response to water conservation and rationing restrictions and the identification and measurement of costs and loss associated with water shortages for major water users; not only for single home dwellers but for apartment dwellers, businesses, nurseries, livestock farms, city administrations, state and local agencies.

A summary of the type of users sampled, the initial sample size, and the number of questionnaires returned gives an insight into the coverage of the more comprehensive survey. (See Table I)

TABLE I
 COVERAGE OF THE DEPARTMENT'S
 COMPREHENSIVE SURVEY IN MARIN COUNTY

Water Users	Date of Mailing Questionnaire	Area Sampled	Number in Initial Sample	Number of Questionnaires Returned
Single homes	3/17/77	MMWD's Service Area	8,918	4,566
Apartments	3/17/77	"	442	191
Businesses	3/17/77	"	735	271
Nurseries	2/14/77	Marin County	60	46
Dairies and Livestock Farms	2/14/77	Marin County & Southern Sonoma County	141	86
Cities	3/15/77- 4/15/77	Marin County	15	8



The findings for a randomly selected sample of 1,000 single dwelling residents from the 4,566 questionnaires returned in response to the mail survey apply to residents in the service area of Marin Municipal Water District who are located in one of its fifteen meter-reading areas shown in Map I.

CONTEXT AND PERSPECTIVE

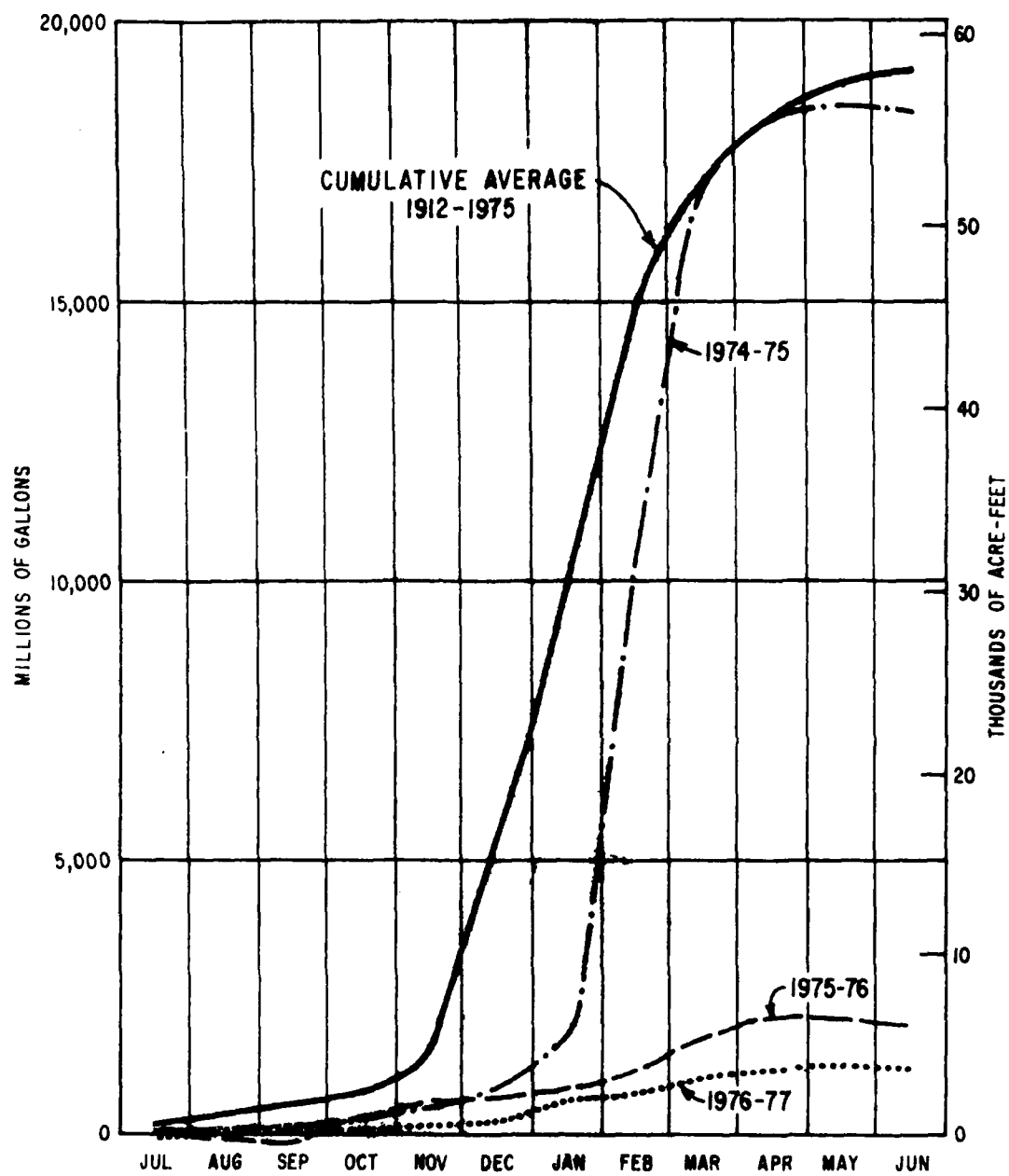
Physical Water Conditions for the District from 1975 to 1977

The physical water supply conditions for Marin Municipal Water District provides the interesting backdrop which throws into relief the rationing and conservation measures which have been applied there.

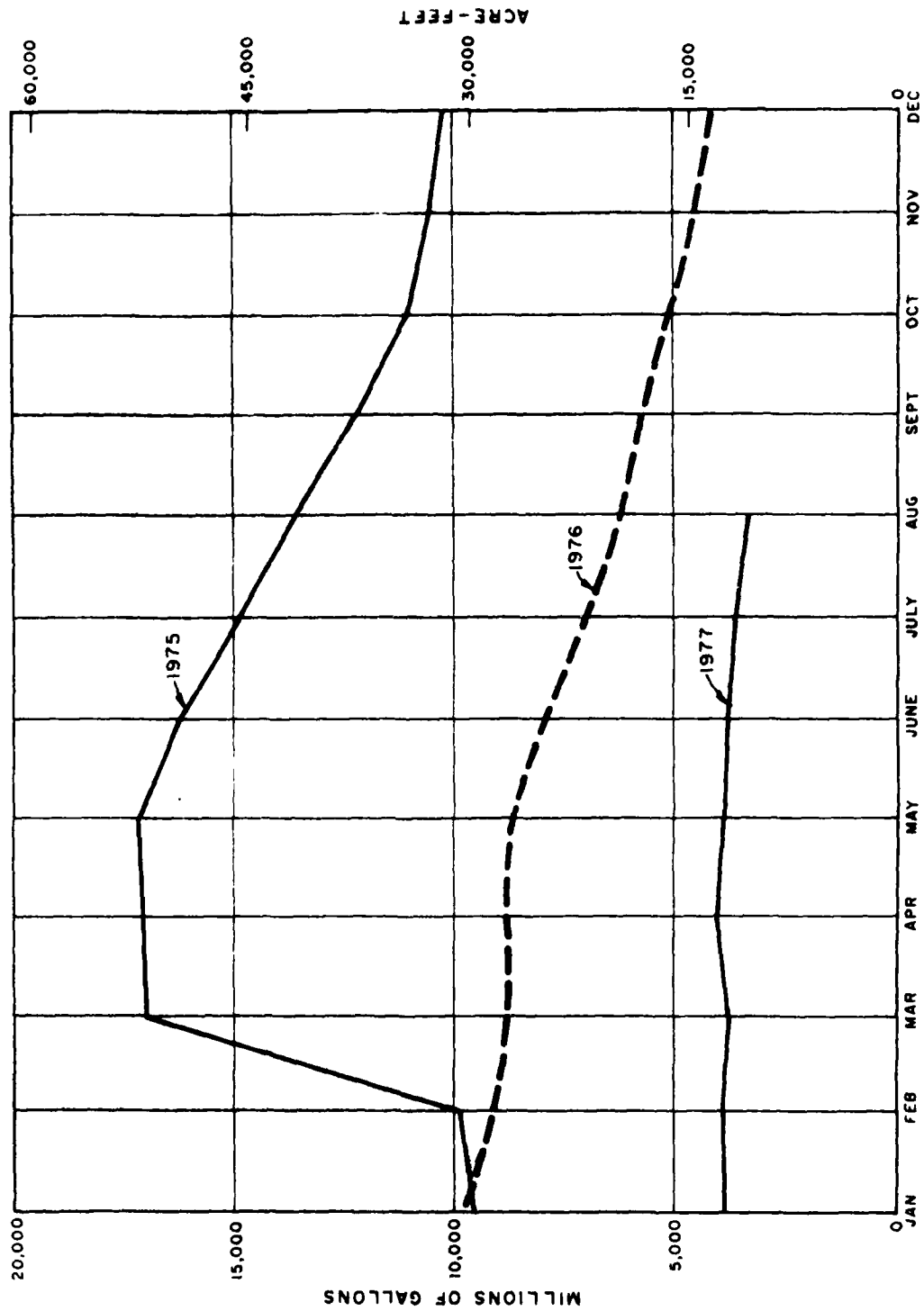
Graph 1 displays forcefully the extent of reduced runoff on the two watersheds, Lagunitas and Nicasio, which supply the District's five reservoirs for a total storage of 52,400 acre-feet. When this is matched with the storage in these reservoirs over recent time the extent of the problem Marin Municipal Water District had (and to a lesser extent still has) in reducing water consumption to levels commensurate with available supply is clearly discernible.

The amounts of water stored in Marin Municipal Water District's reservoirs each month over the 31 month period from January 1975 to August 1977 are shown in Graph 2.

After runoff from the winter rains 1974-75 storage peaked at 17,137 acre feet; it declined gradually from May 1975 to



GRAPH I. COMBINED RUNOFF LAGUNITAS
AND NICASIO WATERSHEDS



GRAPH 2. RESERVOIR STORAGE
MARIN MUNICIPAL WATER DISTRICT

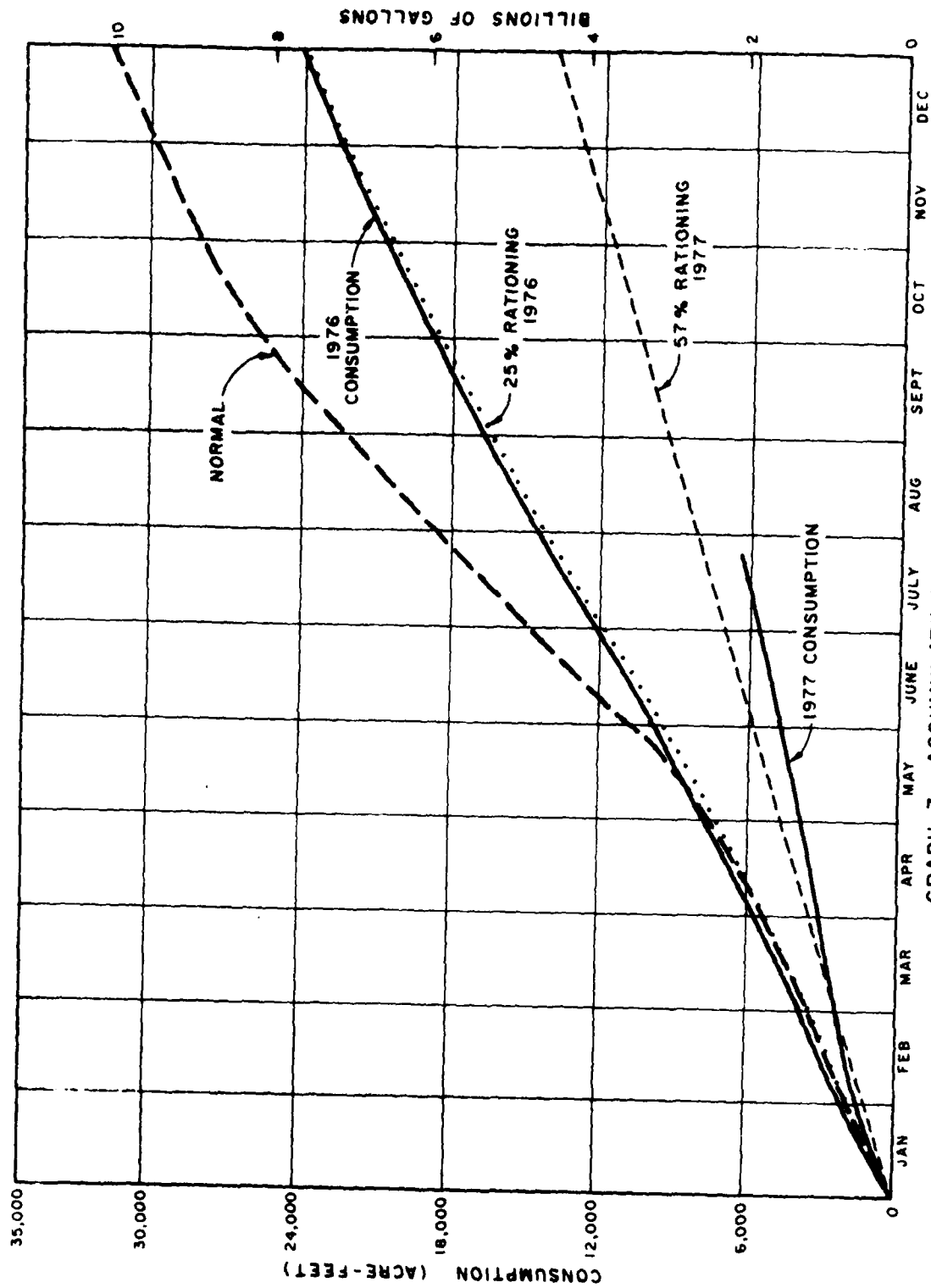
February 1977 when stringent rationing came into force. Since February 1977, water in storage has remained fairly stable at around 3,900 acre feet, reflecting the effects of small supplemental supplies from an intertie with North Marin Water District, the effectiveness of the rationing program in reducing consumption, and in more recent months, the delivery of water via the pipeline across the Richmond-San Rafael Bridge since early June.

The comparison of actual water consumption within the District and the consumption levels set as target for the different rationing programs employed in 1976 and 1977, point to the efficacy of the plans to reduce consumption. (See Graph 3)

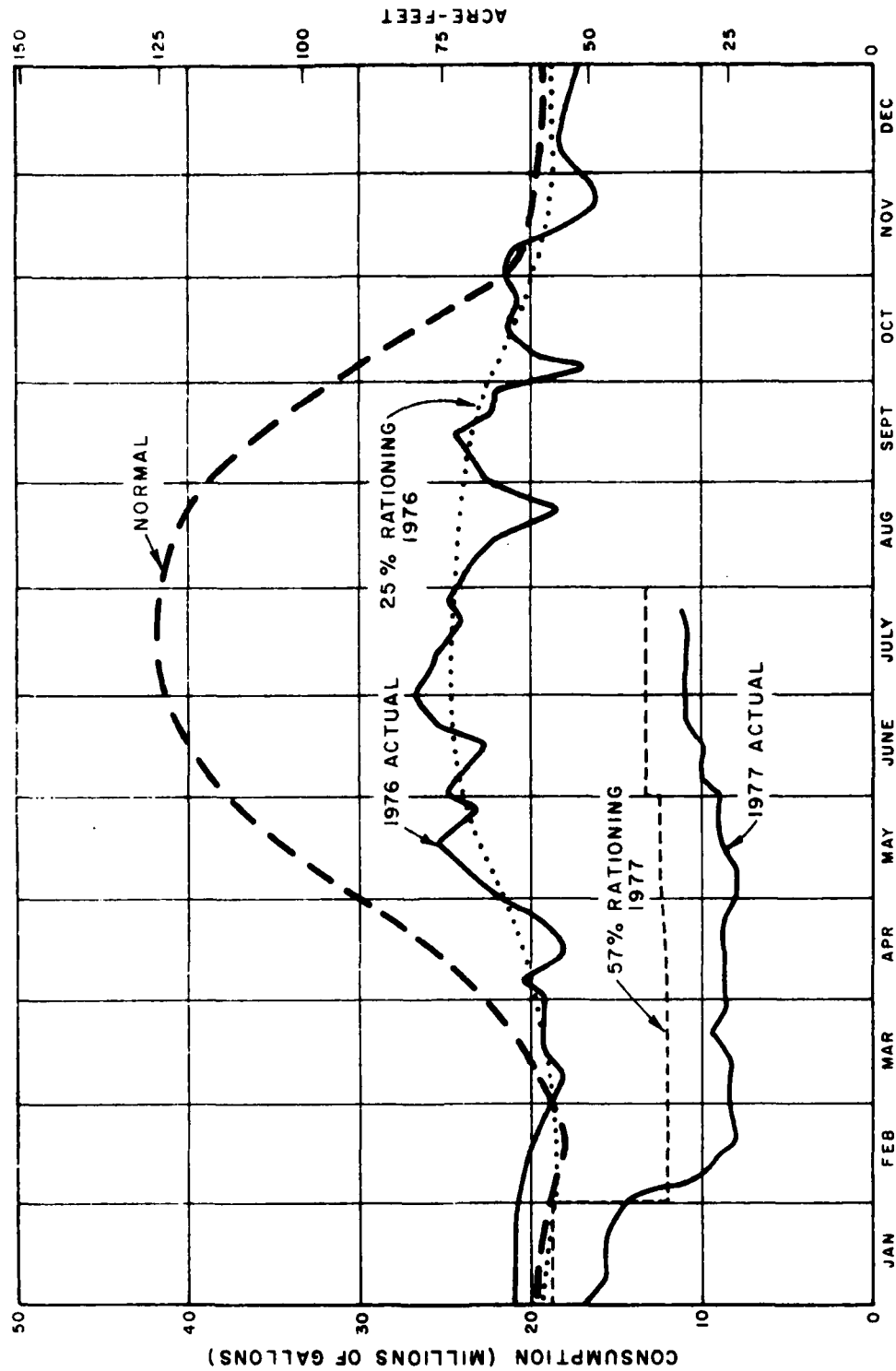
In 1976, actual consumption corresponded with planned consumption representing a 25 percent reduction from consumption in a normal water year. The actual reduction in consumption achieved in 1977 has exceeded the targeted 57 percent of normal. It is closer to 63 percent.

In 1976, peak water use in summer months was reduced by the banning of garden sprinkler systems, the washing and hosing of hard surface areas, and the prohibition of filling swimming pools. The effectiveness of the rationing in reducing peak water use in these months is clear in Graph 4.

An effective rationing program must be designed to impact upon those water uses where a quick change can be brought about where water is used in "excess" and where the costs of curtailing use are not judged immoderate. The level of costs



GRAPH 3. ACCUMULATIVE CONSUMPTION
MARIN MUNICIPAL WATER DISTRICT



GRAPH 4. WATER CONSUMPTION
MARIN MUNICIPAL WATER DISTRICT

the community is willing to bear in a water short period is a function of level of credibility of the seriousness of the supply situation. The latter, knowledgeability and awareness of the actual conditions of water supply, is a significant factor in community receptivity and response to rationing. Water District management (in conjunction with the media) played a skillful and insightful role in carefully delineating the options open to them in stretching the limited supplies.

Rationing Measures to Reduce Water Consumption

As the drought increased in intensity and with dwindling water supplies, Marin Municipal Water District had little option other than to initiate rationing measures to cut back on water consumption. An intertie with North Marin Water District gave little respite. Finally, in June 1977, the pipeline across the Richmond-San Rafael Bridge was completed to provide assured supplies but insufficient to allow a lifting of stringent rationing which, as of February 1, 1977, required a 57 percent reduction of normal consumption.

A brief summary of the principal ordinances adopted and the consequent or subsequent price increases provides an insight into the adjustments that were made as water supply conditions worsened. Since March 1, 1976, the price has almost tripled from \$.46 per 100 cubic feet to \$1.34 per 100 cubic feet as of October 1, 1977. The elements of the rationing scheme were changed in the 1977 version. Water users were set a per capita allotment of 46 gallons to be used in any use the user chose.

This was a radical departure from the 1976 rationing scheme which prohibited "nonessential" uses--sprinkling of gardens and hosing of paved surfaces, side walks, etc.

Water use in the service area has been subject not only to the actual prohibition of nonessential uses, penalties and other incentives curbing water consumption, but simultaneously to an intensive educational and retrofitting program and campaign to conserve water. Community and media efforts have heightened the awareness of the water shortage, the need to conserve, and communicated various ways of saving water. The impacts of the conservation measures are difficult to distinguish from the impacts on water use stemming from rationing.

A summary of the principal elements of the rationing programs as they have evolved since February 11, 1976, together with price increases is given in Table II.

Relevance and Purpose

Why should the Department of Water Resources be interested in what really is the prerogative and function of a water district? The chief reason is that for the first major drought in some thirty or more years, the lessons learned today are important for application should the dry period persist or recur in the immediate future.

Identification and documentation of the effects of the drought and the responses to rationing measures reveal to other water agencies feasible paths to follow should exigencies of

TABLE II
SUMMARY OF RATIONING ORDINANCES BY
MARIN MUNICIPAL WATER DISTRICT IN
1975 and 1976

Effective Date	Rate Change (per 100 cu. ft.)		Water-use Restrictions/Penalties
	Previous Rate	New Rate	
<u>1976</u>			
2/11	-----	-----	Prohibition of waste, non-essential uses (gutter flooding). Disconnection of service after two warnings.
3/1	\$.46	\$.61	Regular rate Prohibition of non-essential uses: 1. Sprinkler systems: hand-held hose only. 2. Washing or hosing of hard-surfaced areas and motor vehicles except with 3 gallon container. Disconnection of service after two warnings.
4/28	-----	-----	Prohibition of filling any swimming pool emptied on or after April 29.
7/28	.61	.61/.84*	*Two-step (peak load) residential rate structure: .61 up to bimonthly usage ceilings established for the 5 residential classes. .84 for water usage in excess of these usages.
7/28	-----	-----	Filling of any new swimming pool prohibited.
<u>1977</u>			
2/1	.61/.84	1.22	Regular rate Penalty rate structure: \$10.00 per 100 cu. ft. used in excess of allotments--up to twice said allotment. \$50.00 per 100 cu/ ft. in excess thereof.

TABLE 11 (cont'd)
SUMMARY OF RATIONING ORDINANCES BY
MARIN MUNICIPAL WATER DISTRICT IN
1975 and 1976

Effective Date	Rate Change (per 100 cu. ft.)		Water-use Restrictions/Penalties
	Previous Rate	New Rate	
<u>1977</u>			
2/1	-----	-----	a) Bimonthly usage allotments established for each class of water user b) Non compliance to result in service disconnection and installation of flow restrictor. c) General Manager may grant variances or adjust allotments.
6/1	-----	-----	Bimonthly usage allotment to non-residential users increased.
7/1	-----	-----	Rules for termination of service eased
8/1	1.22	1.34	Regular rate.
10/1	1.34	1.87 1.87	For consumption over 400 cubic feet an additional \$.53 per 100 cubic feet pipeline charge is levied to pay for pipeline conveying water across the Richmond-San Rafael Bridge.

similar dimensions arise. The Department as a water management and development agency has a need for such basic knowledge and is in an advantageous position to make this information available to water supply entities.

Also, in future planning for water supply, it is important to know what can be achieved by different conservation measures insofar as levels of water use are involved. Given the experience in the drought, will per capita water consumption for different users return to the level of former normal water years when, hopefully, water conditions again become normal? How much water per household can people live with and still maintain the quality of life they have known under better water days? Answers to these questions were sought as an essential part of the study. Another principal thrust of the survey was to document the additional costs incurred and actual losses sustained as a result of the drought. The costs and losses borne by householders up to March 31, 1977, chiefly for landscaping, have been compiled; however, the costs and losses have increased considerably since that time as the drought has continued. A usefully complete accounting possibly should not be made until well into 1978 when the full effects are better known. Should the drought persist through the winter of 1977-78, the time for initiating the assessment must be deferred until the winter of 1979. For this reason, the present study

does not provide any information on the economic costs and losses of the drought as they were appraised up to the end of March 1977. ^{3/}

To accomplish the overall objective--to identify and document the effects of drought and water shortage on single dwelling residents in Marin Municipal Water District's service area, the actual changes in domestic water use and in practices and technologies under the different rationing regimes had to be identified.

An appraisal of the conservation measures undertaken by households and their effect in reducing water consumption complimented the investigation of the changes householders made to comply with the rationing ordinances.

The analysis and interpretation of water consumption for households has to account for different family sizes, incomes, garden sizes requiring water, different numbers and combinations of water-using appliances, existence of a swimming pool, the timing, number and type of "watersaving" devices installed, in addition to the more difficult quantifiable condition, the level of education and attitude of members of the household to conserving water.

The findings as reported, subsequently are preliminary. They are concerned with description rather than analysis.

^{3/}A summary of the costs and losses sustained by 68 dairy and livestock farmers as of March 1, 1977, in Marin County is presented in a preliminary report entitled: "Findings of Mail Questionnaire Survey to Ascertain Effects of Drought on Dairy Farmers and Ranchers in Marin County". This report was submitted to Marin County Board of Supervisors in April 1977. A copy is appended to this paper.

Statistical analysis which seeks to disentangle the many factors influencing water consumption has not been applied except in an elementary way. The data is presented in simple tabulations which aim to show the relationships between water consumption and the many factors which affect it.^{4/}

FACTORS AFFECTING CONSUMPTION

Temperature and Precipitation

In Marin Municipal Water District's service area climatic variability might be assumed to be one of the principal determinants of variation in water use from one community or area to another, especially in summer months when landscaping requires additional moisture. Service areas in the southernmost part of the district--Sausalito, Tiburon, Corte Madera, Greenbrae--have generally lower temperatures (particularly during the summer months), moderate precipitation in the "rainy months" and relatively greater cloud cover persisting in the summer due to fog which blankets areas close to San Francisco Bay and the coast.

Temperature increases while precipitation decreases slightly in the northern service areas--San Rafael, Terra Linda and Marinwood. Temperature and precipitation both increase in the western reaches of the water district--Fairfax, San Anselmo and San Geronimo Valley.

Some indication of the partial effect of temperature on water

^{4/}The full range of relevant statistical techniques will be applied to obtain a detailed understanding of the relationships between water consumption and the many factors influencing it.

consumption is discernible from Table 3 where the daily consumption of water per person for the normal water year 1975 is contrasted with mean average temperature for the summer months of June, July, August, and September 1975 for each of the fifteen regions.

As must be emphasized repeatedly, water use per household and per person is the result of a great many factors, even in summer months where increased water use reflects largely the increased demands for outside watering.^{5/} For the normal water supply year 1975, with the exception of the Ross-Kentfield and Sausalito areas, the average daily water consumption fell within the range of 100 to 130 gallons. The Ross-Kentfield area recorded the highest average per capita consumption - 172 gallons daily, and Tamalpais Valley registered the lowest - 80 gallons daily.

Household and Population Characteristics

The characteristics of the households sampled is another important consideration influencing average daily per capita water consumption. The economic status of households, the size of the lot requiring water, the ownership of a swimming pool, and the number and combination of water-using appliances in the home can be expected to influence water consumption. The age distribution of members of the household, especially if members are retired, and the size of the household are also important determinants of daily water use per person.

^{5/} In planned statistical analysis, partial correlations and the estimation of beta coefficients from multivariate regression should indicate the relative influence of each of the variables found significant.

TABLE III
DAILY WATER CONSUMPTION PER PERSON
AND MEAN SUMMER MONTH TEMPERATURES - 1975

Region	No. of Households	Average Daily Water Consumption per person in gallons	Average Monthly Summer Temperature Degree Fahrenheit (high-low)
San Geronimo Valley	26	100	78.4 - 48.7
Fairfax	55	110	81.4 - 55.3
San Anselmo	108	130	81.4 - 55.3
Ross, Kentfield	52	172	81.1 - 50.1
Larkspur, Corte Madera	67	95	74.7 - 52.5
Mill Valley	120	103	72.9 - 48.5
Tamalpais Valley	49	80	70.9 - 50.3
Sausalito	44	99	70.9 - 50.3
Tiburon, Belvedere, Strawberry Pt.	113	130	70.9 - 50.3
Greenville	33	130	74.7 - 52.5
San Rafael	150	139	78.7 - 53.1
San Rafael, Glenwood	25	132	78.7 - 53.1
Santa Venetia	36	132	83.8 - 50.7
Terra Linda	60	131	83.8 - 50.7
Marinwood Lucas Valley	54	121	85.1 - 49.1

TOTAL CASES: 992*

*Eight households did not give information on the number of residents in that household

In the different meter-reading areas sampled family income varies appreciably. In Ross, Kentfield, Tiburon and Belvedere, the highest income groups have their residences, while the lower income groups tend to be located in the more remote northerly and westerly service areas of Santa Venetia, San Geronimo Valley and Fairfax.

While average daily water consumption per person in the normal year 1975 does not vary greatly for the majority of the areas (13 out of 15), the average masks the great variations in daily water use when measured in terms of per household use. Differences in family income and its many associated features, such as number of water-using fixtures and appliances, swimming pools, and size of lot requiring water for lawns and gardens, have significant effects on water use in normal water supply years. Even under "moderate" rationing conditions which prevailed in 1976 the tendency persisted for higher income groups, i.e., those above \$35,000 annual family income, to use more water per person (see Table 4). While income groups below the level of \$35,000 used 80 to 90 gallons, the two highest income classes used 103 and 122 gallons per person.

In the strict rationing scene of 1977, with daily allotments of water set at 46 gallons per person irrespective of income, people used the same amount of water daily - 26 to 31 gallons. The remarkably low consumption levels relate to the first four months (some 120 days) after February 1, 1977, when stringent rationing came into effect. Water use in the summer months of 1977,

TABLE IV
DAILY WATER CONSUMPTION
PER HOUSEHOLD AND PER PERSON
BY FAMILY INCOME CLASS

	FAMILY INCOME					
	Less Than \$10,000	\$10,000-\$15,000	\$15,000-\$25,000	\$25,000-\$35,000	\$35,000-\$50,000	Greater Than \$50,000
Water Consumption Per Household	Gallons Per Day					
1975 - Normal	232	289	320	377	460	579
1976 - Rationed to 75% of Normal	163	213	237	287	335	437
1977*- Rationed to 43% of Normal	58	69	82	91	91	115
Water Consumption Per Person	Gallons Per Day					
1975 - Normal	118	121	112	118	141	164
1976 - Rationed to 75% of Normal	82	88	81	88	103	122
1977*- Rationed to 43% of Normal	28	28	26	26	28	31

*The consumption figures for 1977 relate to a period of 120 days after February 1, 1977, when stringent rationing of 46 gallons per person came into effect.

June to September, is not included in the estimate given in Table 4. Daily water use for the summer period recorded by the District indicates that water consumption has increased only slightly.

Several of the significant determinants of water consumption are shown in Table 5 for each of the family income classes recorded in the survey. As income increases there is an increase in the "potential" to use more water per household. Planning for water consumption in a normal water year has to be cognizant of the income structure of the community. It is also apparent from the experience of Marin Municipal Water District that rationing based on an allotment per person can be successfully applied to all income groups. What is not shown and what is important, are the losses and costs the different income groups have suffered in complying with rationing ordinances. It might be expected that the higher income groups have incurred large costs in terms of landscaping losses, since the areas of garden and lawn requiring water are quite large (exceeding 12,000 square feet), for that group which has a family income exceeding \$50,000 annually.

TABLE V
SELECTED WATER-USING HOUSEHOLD
CHARACTERISTICS BY FAMILY INCOME CLASS

Characteristics and Number of Households	Annual Income After Taxes					
	Less Than \$10,000	\$10,000-\$15,000	\$15,000-\$25,000	\$25,000-\$35,000	\$35,000-\$50,000	Greater Than \$50,000
Average No. of Water Using Appliances *	6	8	9	10	11	12
No. of Households Responding (Total Cases: 761)	107	126	283	182	102	61
Average of Lot Requiring Water	4,100	6,500	5,700	6,700	7,600	12,300
No. of Households Responding (Total Cases: 763)	95	110	247	170	89	52
Average Assessed Property Value	\$44,700	\$54,000	\$60,200	\$72,000	\$88,700	\$104,300
No. of Households Responding (Total Cases: 763)	94	111	247	165	92	54
Average Market Value	\$52,600	\$63,100	\$74,800	\$92,600	\$113,800	\$136,500
No. of Households Responding (Total Cases: 694)	81	99	224	153	80	47
Percent That Have Swimming Pools	5.9	8.5	10.8	17.4	29.1	36.5
No. of Households Responding (Total Cases: 894)	118	130	286	184	103	63

*Includes bathroom fixtures, laundry and kitchen appliances.

The number of persons occupying a dwelling, whether those persons are away from home during the day, and the length of vacation and time of vacation affect per capita water consumption.

Household water consumption increased as the number of persons living in a dwelling increased; however, this increase occurred at a decreasing rate. The greater the number of people in a household, the lower the per capita water consumption.

TABLE VI
AVERAGE DAILY WATER CONSUMPTION
PER HOUSEHOLD AND PER PERSON
BY HOUSEHOLD SIZE

No. of Persons in Household	No. of Households	1975		1976		1977 ^{1/}	
		Per Household	Per Person	Per Household	Per Person	Per Household	Per Person
1 ^{2/}	82	187	183	128	125	52	50
2	326	278	139	192	96	75	37
3	197	353	117	267	88	111	37
4	223	403	100	309	77	136	34
5	113	484	97	371	74	162	32
6	35	531	88	408	68	203	34
7	11	567	81	436	62	164	23
8+	5	558	60	487	45	289	27

^{1/}For the period from January 1, 1977 up to and including 120 days after February 1, 1977.

^{2/}The small discrepancy between the consumption per one member household and per person is attributable to including in the per person estimate any part time occupancy of that residence.

In the normal water supply year 1975, a one member household used on the average three times as much water per person as households which had eight or more members--183 gallons per day compared to 60 gallons per day. Approximately the same ratio prevailed for these two household sizes in 1976, when water was moderately rationed--145 gallons per day compared to 45 gallons per day.

The water consumption figures shown in Table VI are translated graphically in Graph 5.

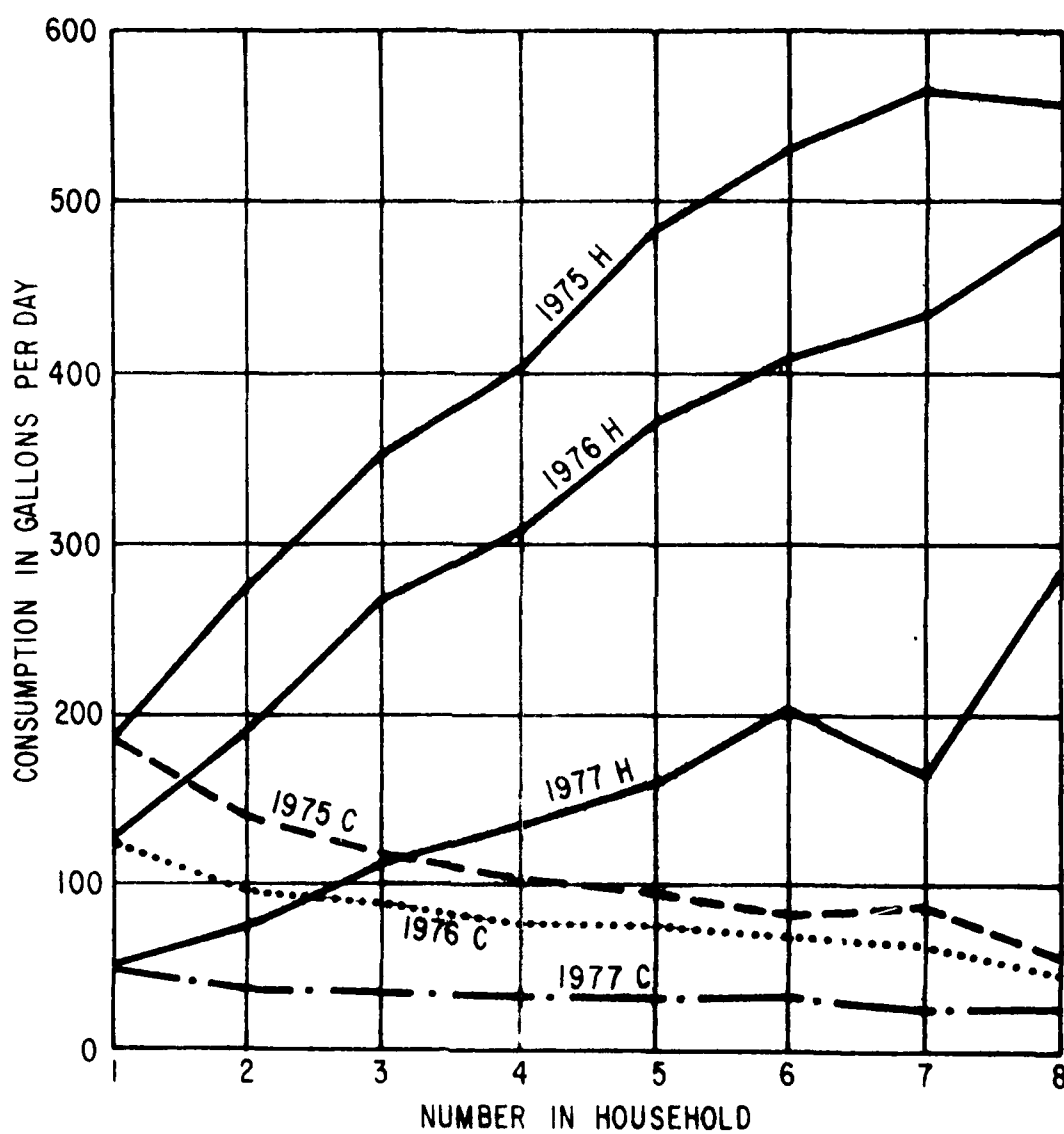
Some idea of the extent to which consumption per household is related to each of the following factors--household size, lot size requiring water, existence of a swimming pool, and family income--and of the relative importance of each of these "independent factors", was sought.

The approach adopted consists of determining what part of the variance in household consumption is explained by each variable, based on a technique for segregating the explained variance into components explained directly and components explained indirectly by each of these factors.

The percent of the variation of consumption per household which can be accounted for by each of these four factors is shown in Table VII, for each year. As might be expected, from 1975 through to 1977 household size increasingly assumed importance as a predictor; the relative effect of lot size requiring

H = PER HOUSEHOLD

C = PER CAPITA



GRAPH 5. DAILY WATER CONSUMPTION PER HOUSEHOLD
AND PER CAPITA FOR 1975-1976-1977

TABLE VII
PERCENT OF VARIANCE IN HOUSEHOLD WATER
CONSUMPTION EXPLAINED BY SELECTED FACTORS

Determinants of Water Consumption	1975	1976	1977
Household Size	15.2	21.9%	34.1
Lot Size Requiring Water	11.7	10.1%	1.2
Swimming Pool	4.5	4.5%	2.7
Income	3.1	3.1%	1.2
Total Percent of Variance Explained by the Factors	34.5	39.6%	39.2

In each of the years, the F-ratio generated by the multiple R^2 from the regression equation was significant at the .01 level.

water diminished. Prohibition on garden sprinkling in 1976 and then in February, the rigid setting of 46 gallons per person would have such an impact.

It must be pointed out that many of the determinants of water consumption were not specified in this partial relationship subjected to regression analysis; these factors explained only about 40 percent of the variance in consumption. The number of water-using appliances in the household, the number of water-saving devices installed, the use of other sources of water other than the District's supply, the age distribution of household members, and other factors, were not included.

DROUGHT TIME CONSUMPTION: IMPLICATIONS FOR FUTURE WATER DEMANDS

In addition to appraising the reductions in water consumption induced by rationing and conservation measures taken to cope with the drought, the survey sought to find out whether the changes made by the community might have enduring effects, i.e., future water demands would not be as high as they were projected prior to the drought.

Each respondent to the mail questionnaire survey was asked to indicate how many gallons per person per day members of that household "could conveniently live with in future years when a water shortage no longer existed".

So that each respondent would have a base line on which to make a reasoned judgment, the question was prefaced by information giving the average daily use per person in MMWD's service area, viz:

125 gallons in 1975 (prior to water shortage)

92 gallons in 1976 (mandatory rationing to 75%
of normal)

40 gallons in 1977 (stringent mandatory rationing
to 43% of normal)^{6/}

Eighty-eight percent of the households responding to the question, i.e., 818 out of 918 households considered that, given their recent experience, with little inconvenience, 100 gallons

^{6/} The crude estimates were supplied by the District. They were obtained by dividing average daily water consumption by the estimated population in each year. The actual consumption levels found for 992 households in the 1000 household sample compare as follows: 122 gallons in 1975; 88 gallons in 1976; and, 37 gallons in 1977.

or less per day would be sufficient for their needs. Ninety-seven percent of respondents estimated 125 gallons or less would suffice. (See Table No. 8)

While it would be premature to draw conclusions as to the enduring effects of this community's experience on future water demands when water supply conditions return to normal, there are certain incontrovertible facets of the response households have made to cope with the water shortage. Water-using habits have changed; the community is knowledgeable and aware that certain water using practices can be performed with less water and that changes do not necessarily have to be drastic to effect substantial water savings; there is little reason to remove efficient water saving devices especially where there is a concomitant saving in energy.

And over and above these considerations, the price of energy and the price of water are moving upward to reinforce the present trend to use less water. It is a reasonable assumption that residential water demands in future years will not be represented (if they ever were) by linear trends which treat pre-drought consumption levels as a relevant basis for projection.

The drought experience in Marin County has shown that people can live with less water than previously thought adequate. Eighty percent of the 1,000 households sampled consider a per capita water consumption of less than 46 gallons a day moderately inconvenient or not inconvenient. Twenty percent of the households considered the allotment of 46 gallons per day as prescribed in the ordinance

which came in effect on February 1, 1977, to be extremely inconvenient or the cause of great hardship.

TABLE VIII
ESTIMATION OF FUTURE DAILY WATER
USE PER PERSON IN NORMAL WATER YEAR

Gallons/Person/Day	Number of Households	Frequency (Percent)	Cummulative Frequency (Percent)
0- 25	20	2.2	2.2
26- 50	169	18.2	20.4
51- 75	206	22.2	42.6
76-100	423	45.6	88.2
101-125	85	9.2	97.4
126-150	12	1.3	98.7
151-200	6	0.6	99.3
201-500	7	0.7	100.0
No Response	<u>72</u>	<u>missing</u>	100.0
TOTAL	1,000	100.0	

The drought experience has also changed the attitude to the use of reclaimed water for maintaining lawns and gardens in 1977 and in the future. Ninety-four percent of households responded in the affirmative to their willingness to use reclaimed water for this purpose.

RESIDENTIAL WATER CONSERVATION: RETROFITTING, EDUCATION,
AND INVENTION

The remarkable reduction in consumption achieved by MMWD residents can be attributed to the active educational and retrofitting programs of the district management, in addition to the innovative solutions arrived at by residents independently in response to the water-short situation.

Survey questions sought to identify the changes in household water use practices and technologies to comply with the rationing goals. However, an appraisal of the conservation measures undertaken by households must bear in mind the exceptional awareness existing in the County and cultivated by the water district and media.

Voluntary water conservation has been a goal of Marin Municipal Water District management and included as a vital element of its water supply management planning prior to 1975. The district began a residential retrofit campaign in the summer of 1975 as part of its water conservation program. Water saving kits were distributed door-to-door in two of its service areas; the kits were composed of:

- dye tablets
- toilet bottles
- low-flow showerhead and shower flow-restrictor
- informational brochures
- order forms for additional water-saving devices

The kits were provided free.

With the drought conditions and rationing ordinance of May 1976, MMWD undertook further distribution of kits through mail order forms

(billing insert) and neighborhood depots (fire stations, city halls, nurseries, etc.). With continued drought conditions and stringent rationing in 1977, water-saving kits and other devices have been available at the water district headquarters. MMWD has experienced a heavy demand for devices since January, 1977; water-saving kits have remained free to district customers.

Among the survey questions, residents were asked whether they had installed water-saving devices, the type and rate of installation of devices, and the level of satisfaction (or removal) of devices. Eighty-eight percent of the households sampled indicated they had installed either a shower or toilet device in the home. The types of devices and the dates installed are indicated in Table IX.

TABLE IX
INSTALLATION OF WATER-SAVING DEVICES

Type of Device	Number of Households Installing	Frequency (percent)	Rate of Installation		
			Prior to 3/1/76	3/1/76 to 1/1/77	1/1/77 to 4/1/77
Low-Flow Showerhead	433	49.5	30	178	207
Shower Flow-Restrictor	195	22.3	11	60	104
Toilet Bottles/Dams	814	93.1	54	370	337

It is not too surprising that toilet devices were most commonly installed, and installed earliest as the dry period has continued. Toilet devices are probably the simplest of the devices to install in the home, with the least impact on the householder in terms of

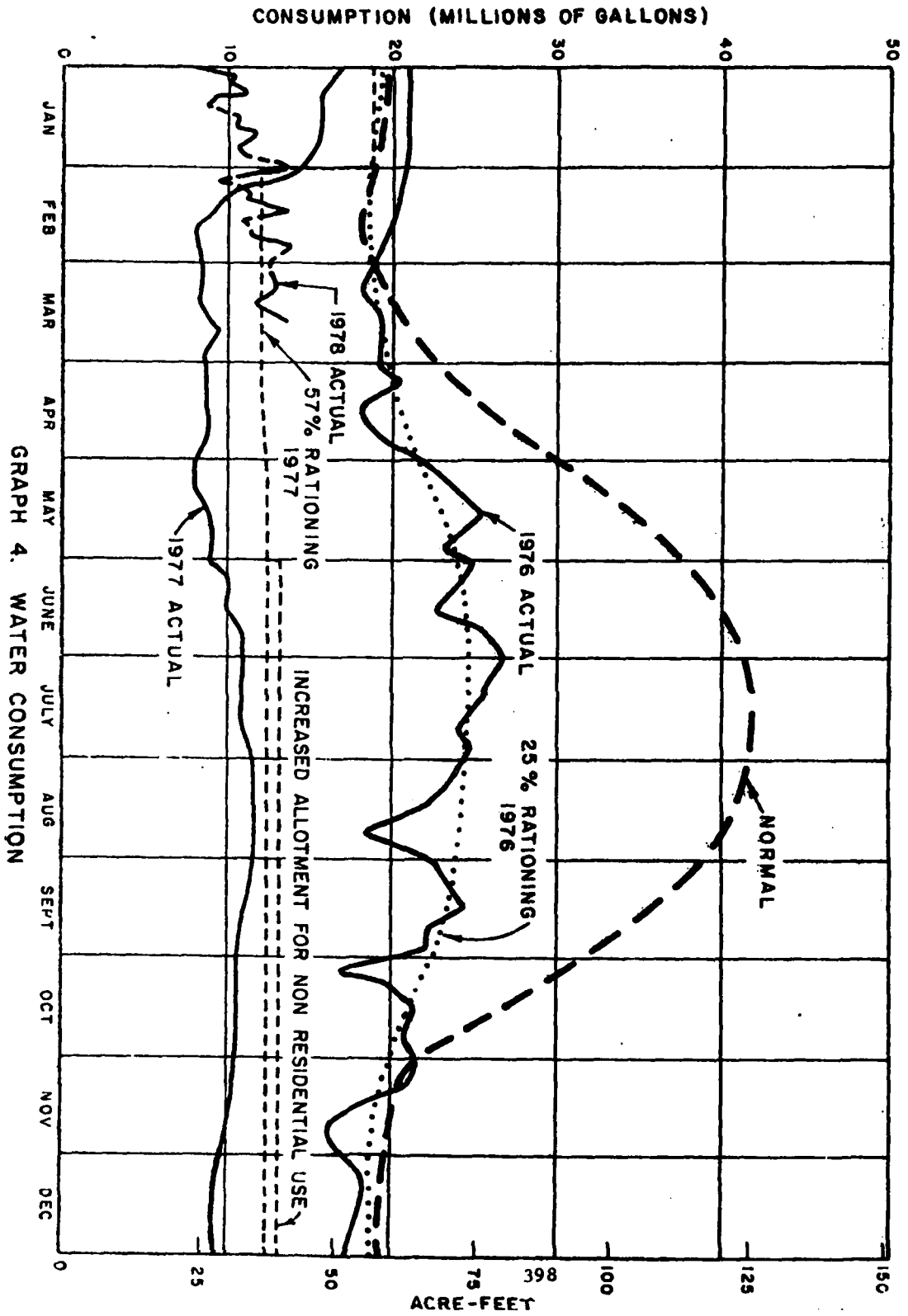
personal inconvenience. As the need to further reduce consumption became apparent early in 1977, households installed relatively more shower devices than toilet bottles or dams.

Eighty-three percent of those installing device(s) indicated they were satisfied with the performance of the device(s); and of those who had installed device(s) and were not satisfied, fifty percent reported that the unsatisfactory device had been removed. Further detail of comments and complaints regarding the devices, along with description of more uncommon plumbing alterations to conserve water, is available.

In addition to an appraisal of retrofitting in homes, the survey sought to find out, in detail, the changes in indoor household water-use habits of practices for 1976 and 1977. Of those responding to the question, seventy-five percent had indicated some change in indoor water-use habits in 1976, and ninety-eight percent in 1977. The number and variety of changes described is quite surprising; most striking is the widespread reuse of household water for exterior use and for toilet flushing.

Finally, each respondent to the mail questionnaire survey was asked which water-saving measures were found to be "most practical and effective", overall. The ten practices most frequently listed are the following:

1. Less frequent toilet flushing
2. Reuse of water (unspecified)
3. Flushing toilet with greywater
4. Reduce amount of water used per shower and/or bath
5. Reduce frequency of showers and/or baths
6. Do laundry less frequently--fuller loads
7. Use greywater outside
8. Using toilet bottles and/or dams
9. Reduce or eliminate garden watering.
10. Education and awareness of the water situation



GRAPH 4. WATER CONSUMPTION

WATER CONSERVATION IN WATER SUPPLY PLANNING

CORPS OF ENGINEERS INITIATIVES IN WATER SUPPLY²

by

Donald B. Duncan, M. ASCE¹

The U.S. Army Corps of Engineers (Corps) is not a novice in the business of providing water supply for municipal and industrial (MCI) use. The Flood Control Act of 1944 authorized the Corps to dispose of surplus water for domestic and industrial use, and numerous water service contracts for withdrawal of small amounts of water have been approved for temporary use of surplus water. Storage for water supply was authorized in projects prior to 1958 on the basis of individual project proposals. The first general authority for inclusion of water supply storage in Corps projects was enacted in 1958. The Water Supply Act of 1958 (Public Law 85-500, Title III) introduced a period of joint-venture development of water resources by federal and non-federal interests. Development for traditional federal purposes, such as flood control and hydroelectric power, was teamed with development of MCI water supplies at non-federal expense. The Water Supply Act of 1958 carefully avoided a shift of responsibility from non-federal interests to federal level of government. The introduction to that Act reads:

"It is hereby declared to be in the policy of the Congress to recognize the primary responsibilities of the States and local interests in developing water supplies for domestic, municipal, industrial and other purposes, and that the Federal Government should participate and cooperate with States and local interests in developing such water supplies in connection with the construction, maintenance, and operation of Federal navigation, flood control, irrigation, or multiple-purpose projects."

Corps reservoir projects include substantial amounts of storage for water supply. Table 1 presents an inventory of this storage and its costs. Approximately 8 million acre-feet (10 billion cubic meters) of storage in 94 projects is under contract. An additional 12 million acre-feet (15 billion cubic meters) of storage in 84 projects is either included in existing projects or will become available if all authorized projects are constructed. The existing contracts obligate non-federal interests to repay more than \$400 million of federal investment costs.

² To be presented at the annual ASCE meeting in Hollywood, Florida, on 27-31 October 1980.

¹ Chief, Policy Development, Office of Policy, Directorate of Civil Works, U.S. Army Corps of Engineers, Washington, D.C. 20314.

TABLE 1

INVENTORY OF WATER SUPPLY STORAGE
IN CORPS OF ENGINEERS PROJECTS

Category (1)	Number of Projects (2)	Acre-feet X 10 ³ (3)	STORAGE Cubic meters X 10 ⁶ (4)	Cost (5)
Storage under contract	94	7,902	9,743	\$438,772,000
Storage - contracts under negotiations	34	2,247	2,771	519,716,000
Storage - not yet under negotiations				
- Operational projects	17	891	1,099	94,091,000
- Projects under design or construction	15	4,358	5,373	649,000,000
- Other authorized projects	18	4,790	5,906	540,000,000
TOTAL	178	20,188	24,892	\$2,241,579,000

Title I of Public Law 89-298, October 27, 1965, authorized a federal and non-federal cooperative study to prepare plans to meet the long-range water needs of the Northeastern United States. The legislation also authorized federal construction and operation and maintenance of certain major facilities that had previously been the responsibility of non-federal interests. This study has produced several water supply proposals; however, the appropriate federal role in implementation of these plans has not yet been established.

Water supply continues to be an important part of water resources studies by the Corps. The fiscal year 1980 budget included funds for about 50 feasibility studies that have M&I water supply as one of the purposes to be studied.

WATER CONSERVATION - A CHANGE

A new era began with President Carter's announcement in May 1977 that water conservation would be the cornerstone of his revised water policy. A comprehensive review of water policy was initiated during the summer of 1977 that culminated in the President's Water Policy Message of June 6, 1978, and by a series of directives to the federal agencies in July 1978.

Why is water conservation an objective worthy of emphasis as a national objective? The basic reason is that new supplies often place demands on other scarce resources that are not adequately reflected in the evaluation of and price for water. These scarce resources include energy, environmental resources, agricultural land, ground water resources, capital, and the beneficial uses of instream flows. The President has pledged that his policy reforms will not preempt state or local responsibilities. On the other hand, the thesis of the new water policy is that federal programs will not foster inefficient use of the water resources of the Nation.

Water is an essential resource. It is an important ingredient in all of the major challenges we face--production of food and fiber, energy, pollution control, transportation, and environmental quality. The growing scarcity of water is well documented. Our ingenuity and skills will be tested to find ways to satisfy the increasing demand for water. Water conservation is believed to be a key element in addressing these demands.

In March 1978, the Corps initiated efforts to integrate water conservation into its activities. The strategy called for the Corps to:

1. define water conservation within the context of the Corps program;
2. develop principles and specific procedures for evaluation of water conservation as part of M&I water supply; and
3. develop a plan of action (POA) for integrating water conservation into all aspects of the Corps program.

DEFINITION OF WATER CONSERVATION

Water conservation is not a new term; however, its use has been so varied that a universal definition has not evolved. Water conservation is different from other forms of conservation. Energy conservation is usually thought of in terms of nonuse so that the resource will be available at a future time. Fish and wildlife conservation provides for use of the resource, but in a manner that preserves and protects the regenerating capability of the resource. Nonuse of water does not automatically insure its availability at a later time, and the regenerating process (hydrologic cycle) is pretty much beyond our ability to manage at this time. The challenge was to develop a water conservation definition and evaluation process that will permit us to make a consistent trade-off between increments of new supply and measures that result in more efficient use of existing supplies.

The temptation to adopt the "wise use of resources" definition of water conservation was avoided. Such a definition would be comprehensive, but open to interpretation, permitting everyone to retain his own traditional perspective of water conservation. Perspectives would range from not using the water resource unless it is essential, to use of the water resource as many times as possible between the time it falls as rain until it is lost or flows into the ocean.

To be helpful, the definition of water conservation must possess two attributes: It must be precise, and it must be practical. Review of numerous publications on conservation (1) lead to the conclusion that the only way that water conservation can be separated from water supply in a precise and practical manner is to consider conservation as management of the demand function (2). The required attributes can be satisfied on this basis via the following definition:

"Water conservation is any beneficial reduction in water use or in water losses."

Based on this definition, water management practices constitute conservation only when they meet two tests:

1. Their purpose is to conserve a given supply of water through reduction in water use (or water loss); and
2. Their total national economic and environmental benefits outweigh their total national economic and environmental costs.

Water use is the withdrawal of water from a supply or other action which denies the availability of that water to another user. Uses range from human consumption to support of fish and the natural environment associated with streams. A reduction in water use is beneficial if the aggregate of all beneficial economic and environmental effects resulting from implementation of the water management practice exceeds the aggregate of all adverse economic and environmental effects occasioned by such implementation. Recognizing that, just as in the case of augmenting supply, conservation measures may deplete other scarce resources (such as energy), the above definition of beneficial reductions will assure that all scarce resources are conserved.

Water supply and water conservation, as defined above, have much in common. Neither can be implemented without making demands on other scarce resources, and the merits of both must be evaluated using the same basic criteria. In addition, the fact that not all new supplies should be considered desirable is also applicable to water conservation measures. The evaluation of the adequacy of existing water supplies and the measures needed to address future water needs requires an assessment of:

1. Demand reduction practices;
2. More efficient utilization of existing supplies; and
3. Need for new supplies.

PRINCIPLES AND PROCEDURES FOR EVALUATION

How are the merits of water conservation to be established? Is conservation good because it is a substitute for new supply? These questions were at the root of much of the controversy that surrounded the water conservation portion of the President's water policy.

Water conservation should be a specific subset of natural resources management. The definition set forth by the Corps is compatible with the President's policy and indicates explicitly that reductions in water use or water losses must be beneficial. The principles and standards for planning conducted by the federal water resources agencies are published by the U.S. Water Resources Council. The prescribed planning objectives are national economic development (NED) and enhancement of environmental quality (EQ). Water conservation has not been exempted from any of the requirements applicable to other water resources functions.

The Corps has developed a detailed manual for an evaluation procedure that permits a consistent and balanced trade-off between water conservation and increments of new supply (3). The manual includes two illustrative examples. The following paragraphs summarize the evaluation procedure.

The evaluation of supply and conservation options may progress simultaneously through much of the process, as shown in Figure 1. The positive and negative effects on NED and EQ are measured by comparing the "with" and "without" conditions. The positive effects of water conservation include the avoidance or postponement of costs associated with providing new supply and additional water and wastewater treatment. In addition, certain energy costs and adverse environmental impacts may be avoided. Negative effects of water conservation include implementation costs, adverse environmental impacts, and reduction in outputs for other purposes that would have been produced by the supply project (such as recreation in the case of a water supply reservoir).

The projection of future water needs is made without adding water conservation measures beyond those already implemented or those involving definite commitments for implementation. Alternative plans are formulated to supply the amount of water identified as the difference between the existing supply and the projected requirements. Several water supply plans are formulated. These include one that emphasizes

GENERAL PROCEDURE : AN OVERVIEW

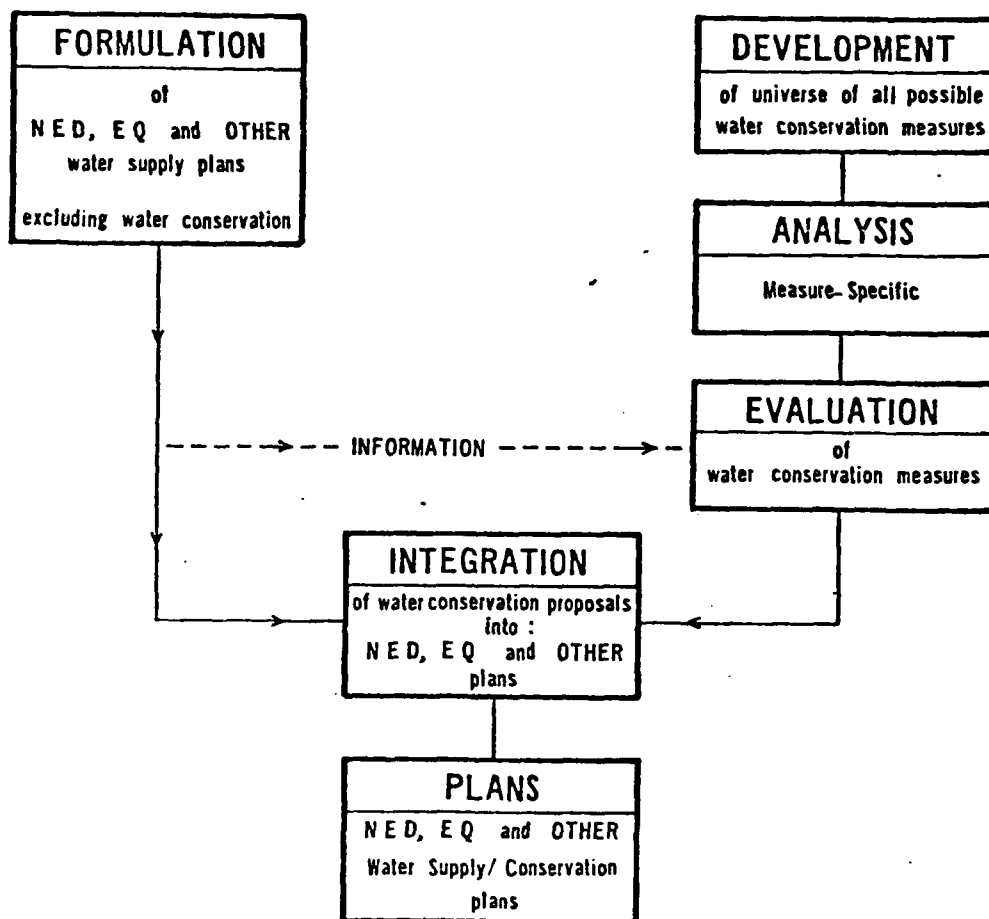


FIGURE 1

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ARMY ENGINEER INST FOR WATER RESOURCES FORT BELVOIR VA F/G 13/2
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NED, another that emphasizes EQ, and others that reflect combinations of NED and EQ.

The evaluation of water conservation starts with the development of a universe of possible water conservation measures (regulation, management, and education). These measures are then tested for applicability, technical feasibility, and social acceptability. The potential measures are those that are applicable to the study area and setting, are technically feasible, and have potential for being socially acceptable.

A measure-specific analysis of the potential measures is made to establish the characteristics of the measures that are independent of the water supply plans. These include the implementation conditions (coverage and duration), the effectiveness of the measure, the costs foregone for water supply, energy savings, the costs foregone for treatment of raw water and wastewater, implementation costs, and environmental effects.

Other positive and negative effects (NED and EQ) of substituting a water conservation measure for an equivalent amount of water supply are dependent upon the specific water supply plan considered. To test all potential measures and combinations thereof for inclusion in several supply plans requires an inordinate number of calculations. A procedure was therefore adopted that reduces the number of calculations and yet retains acceptable limits of accuracy. The procedure is to include each potential measure into the water supply plan one at a time to determine the net change in NED and EQ outputs of the plan that are attributable to that measure. The measures are then ranked in merit order based on their net increase in the desired output. For example, the measure that produces the largest increase in net NED benefits is ranked first for the process of integrating water conservation into the NED plan. Other measures would be ranked according to their impact on net NED benefits. The same ranking procedure would apply to the EQ plan with net positive impacts on the environment being the ranking factor.

The ranking of measures in merit order permits a once-through process for integration of the water conservation measures into the water supply plans to produce plans that maximize the desired outputs (NED, EQ, or a combination of the two). This is accomplished by substituting the measure ranked first in merit order for an equivalent amount of water supply. The increase in net beneficial effects of the plan is then calculated. The second measure in merit order is then substituted after careful consideration of the interactions between the first and second measures. When interactions exist, the incremental effect of the second measure will probably be less than its effect as the single measure. This procedure continues until addition of another measure reduces the net beneficial effects on the plan objective. For the NED plan, measures are added until the next measure would reduce the net NED benefits of the plan. The resulting plan represents the NED plan for water supply/conservation.

The water supply/conservation plans should be tested for compliance with the desired system reliability. Dependability can be designed into plans that include water conservation in the same way that it is included in plans for water supply.

IMPLEMENTATION - PLAN OF ACTION

The national emphasis on water conservation can be separated into two major categories with respect to the Corps water resources program. Sound conservation principles must be applied to the use of water in Corps activities, and water must be an integral consideration in Corps planning to satisfy future water supply needs. This second category translates primarily into an assistance role to state and local governments as a part of studies addressing the adequacy of existing supplies and the need for additions to those supplies.

The Corps issued its first plan of action on May 8, 1979, and a revised edition was issued in May 1980. The POA addresses the relationship of water conservation to the planning of projects and their subsequent construction, operation and maintenance, as well as the regulatory program. The five major activities that constitute the water resources program of the Corps are discussed in the following paragraphs.

PLANNING

The planning role of the Corps represents the greatest opportunity to reduce the demand for additional supplies of water through water conservation practices. While the immediate purpose of water conservation is to better utilize existing supplies, the ultimate effect is to alter water supply planning and use practices. The fact that existing supplies are utilized more efficiently has the effect of postponing and/or reducing the scale of projects designed to augment supply.

A consistent and balanced approach to trade-offs between water conservation and new supply results in changes in the scope of the Corps planning role. Urban areas have been considered traditionally as a unit in water supply studies. Past trends of water use on a per capita or production basis have been projected into the future using general growth predictions. Consideration of water conservation requires a thorough analysis of the water supply, treatment, distribution, use, and wastewater treatment process for the study area. Greater effort and more precision in forecasting demands are required. It will be necessary to separate forecasts into the components of domestic, commercial, and industrial sectors so that conservation measures may be evaluated accurately. It will also be necessary to estimate seasonal water uses separately, and to forecast use in all sectors in terms of several explanatory variables, including price. The Corps must, therefore, become much more familiar with the interworkings of urban water systems than has been the case in the past. This increased involvement will be accomplished in cooperation with non-federal interests rather than federal usurpation of local prerogatives.

The procedures manual developed by the Corps describes the concepts, procedures, and measurement techniques for evaluating water conservation proposals applicable to M&I uses of water. Efforts are underway to improve the manual and to complete several case studies using these procedures.

Non-federal interests will be asked to implement conservation measures incorporated into water supply/conservation plans proposed for construction. Specifically, the President has directed that development of water conservation programs will be a condition of contracts for storage or delivery of M&I water supplies from federal projects.

DESIGN AND CONSTRUCTION

The potential for water conservation associated with design and construction is expected to be project and site specific to the point that generalized standards or techniques will not be appropriate. The potential breaks down into two categories: (1) measures that reduce the use of water; and (2) measures that influence the availability of water (location and/or time).

All Corps field agencies have developed procedures to implement water conservation in the design and construction of Corps projects. A review of the design and construction features of projects will be accomplished during pre-authorization studies, post authorization planning, and design. The water conservation review will be made by an interdisciplinary team of involved professionals with expertise in planning, design, construction, and operations. The objectives are to determine whether changes in the design or construction of the project would produce:

1. additional beneficial water savings; and
2. beneficial improvements in the availability of water.

DROUGHT CONTINGENCY PLANNING

Corps projects provide storage for purposes other than water supply. In fact, only a small percentage of the 263 million acre-feet (324 billion cubic meters) of storage in existing Corps projects is dedicated to water supply (see Table 1). Flexibility associated with this storage represents a valuable resource for responding to short term water shortages in the areas where the projects are located.

The Chief of Engineers has adopted a policy that Corps projects should respond to public needs during droughts to the extent possible under current administrative and legislative authorities. To accomplish this, a two-step approach will be taken to pre-drought planning. The first step will evaluate and establish the limits of flexibility under existing authorities to modify project operations and to use existing storage to respond to short-term periods of water shortages. During droughts, the Corps is asked for information about how its projects can be more responsive to the needs of the public. The second step will establish options for modification of project authority that would permit a progression of additional measures to increase a project's capability to respond to droughts. These studies may also disclose opportunities to reallocate storage to satisfy changing priorities of water resource needs. These opportunities would be studied and appropriate recommendations forwarded to the Congress.

OPERATIONS AND MAINTENANCE

All Corps field agencies are developing a water conservation plan which addresses each project, shop, floating plant, and other separate facility operated and maintained by the Corps. The plan will be directed toward reductions in water use or water losses. The objectives of the plan are to produce beneficial water savings and beneficial improvements in the availability of water. Consumptive uses will be examined, and conservation measures that can be implemented will be analyzed. Modifications to facilities or methods of operation found to meet the two tests associated with the definition of water conservation will be programmed for accomplishment.

REGULATORY

Water conservation is a part of the public interest review for the regulatory program. The question of how water conservation is to be considered in the public interest review is incorporated into the revised regulation, 33 CFR 320 thru 329, that will be published as a draft for comment. Water supply and conservation has been included as one of the specific factors relevant to the public interest review. It recognizes the need for efficient use of water resources in all actions that involve the use of water or that affect the availability of water for alternative uses. Full consideration will be given to water conservation as a factor in the public interest review including opportunities to reduce demand and improve efficiency in order to minimize new supply requirements. The detailed procedures for evaluating water conservation in Corps planning activities will be available for use in any evaluation required to support the public interest review.

FUTURE CHANGE?

The Corps is a unique organization established during the Revolutionary War. Its water resources responsibilities have evolved over a long history of service. The technical expertise of the Corps has been used in the broadening federal interest in water resources, natural disaster and emergency activities, and special missions. There is no reason to believe that the role of the Corps in water resources will remain static, but the exact nature of future change is uncertain. Potential changes related to the federal role in water supply are under active consideration in both the executive and legislative branches.

The President's Water Policy Message of June 6, 1978, called for the creation of an Intergovernmental Water Policy Task Force as a means of continuing the review of water-related problems. Three problem areas were identified by the task force for special study: (1) cost sharing; (2) advanced funding for waste treatment plants; and (3) urban water supply. A subcommittee, under the leadership of the Secretary of the Army, was established to address the problems of urban water supply. The subcommittee was directed to: (1) inventory existing federal programs that have potential for assisting urban water systems rehabilitation or new construction; (2) evaluate the institutional and financial problems surrounding the supply and distribution of municipal water; and (3) assess policy or program changes that might be indicated at the federal,

state or local level in order to address the problem. The subcommittee completed its report in June 1980 (4).

The principal findings of the subcommittee were that:

1. Urban water system capital expenditures needed over the next 20 years are estimated to total \$75-\$110 billion. This includes replacement and rehabilitation of distribution and treatment systems at \$50-\$80 billion, servicing growth at \$5-\$8 billion, upgrading to improve drinking water quality at \$425 million, and new source development at \$20-\$25 billion (1979 dollars).
2. Rough estimates suggest that as many as two out of ten urban water systems might experience capital investment shortfalls over the next 20 years. An investment shortfall is that portion of the capital investment estimated to be needed which a system is judged unable to finance based on its projected expenditures and on revenue increases up to a doubling of rates. The historical significance of such a ratio of shortfall is unknown.
3. The most probable estimate of urban water system capital investment shortfall over the next 20 years, based on rough order-of-magnitude estimating techniques, is between \$10-\$13 billion. The shortfall could range between \$5-\$26 billion, since estimates are both difficult and uncertain without a city-by-city analysis.
4. Of the total estimated national shortfall, about one-half is attributed to distribution system needs and one-third to new source development needs.
5. Municipally-owned and operated water systems are four times as likely as privately-owned systems to experience shortfalls. Regional public systems are twice as likely to experience shortfalls as private systems. Publicly-owned systems currently account for 73 percent of all urban systems and serve 81 percent of the population of urban areas.
6. Federal categorical programs which supply assistance specifically for water supply purposes have limited applicability to urban water supply problems. Farmers Home Administration programs are focused on communities smaller than those classed here as urban (over 50,000 population). Federal water resource development agency programs of direct construction, by policy, do not develop projects for single-purpose water supply.
7. Some federal assistance programs do provide substantial sources of funding assistance which could be directed to water supply. Use of such assistance for water supply purposes depends upon whether State and local governments are able to give such use a high priority relative to other needs for the funds. Economic Development Administration programs, HUD community development programs and Treasury's General Revenue sharing programs provide very large resources which could be used for water supply.

purposes. In FY 1977, nearly \$10 billion went to State and local governments from these programs; about two percent of these funds appear to have been allocated to water supply purposes. Of the \$10 billion total, only \$6 billion was available to urban areas (cities over 50,000), of which the amount utilized for urban water supply is unknown.

On the basis of the subcommittee findings, the following five possible policy approaches were set forth for consideration in response to the problems:

1. Status Quo - This approach would retain existing financial, regulatory, and institutional relationships to continue full local responsibility for water supply.
2. Modified Policies and Programs - Modify existing policies and programs to increase federal technical and planning assistance and condition existing direct federal, grant, and loan programs that are used for urban water supply on state review of urban water system utility rate and investment policies.
3. Federal/State Water Banks - Create federal/state water banks to make capital investment funds more easily accessible to urban water systems. Conditions could be attached to loans requiring conservation to reduce future capital investment practices. Interest subsidies also could be provided for particularly distressed urban areas.
4. Financial Assistance - Implement increases in existing programs or add new programs of federal financial assistance providing grants, loans or loan guarantees, conditioned upon the establishment of conservation programs to reduce future capital investment needs and establishment of self-sustaining rate and investment practices.
5. Single Purpose Water Supply - Remove existing policy prohibitions against single purpose water supply in federal water projects and allow direct federal construction of single purpose water supply projects. Change federal policy to permit the inclusion in federal projects of wellfields, purification and distribution facilities, as well as reservoir source development and major conveyance projects. Change federal policy to permit repair and rehabilitation as well as major reconstruction of such facilities. States would determine, with local input, water supply priorities, and costs would be repaid over time in accordance with the Water Supply Act of 1958.

The subcommittee indicated that selection and implementation of any one or combination of policy approaches by policymakers should occur in conjunction with a more detailed study of urban water resource problems to reduce uncertainties as implementation proceeds. Such a study should be designed to: (1) relate urban water supply problems and solutions to other urban infrastructure problems; (2) inventory on a case-by-case basis urban water system needs; and (3) provide a basis for review of, and "mid-course" correction to, the approach or approaches selected.

Because of the broad inputs from representatives of states and cities as well as federal agencies, the study should prove highly useful to the Administration, Congress, and other interested parties as present policies are reassessed.

The Congress has also taken a special interest in the water supply problems facing the Nation. Numerous bills have been introduced in the 96th Congress that would, if enacted, modify the Corps role related to water supply/conservation. Several of these bills are summarized below:

HR 4788, House passed Water Resources Development Act (WRDA). (some of the same provisions are included in the Senate version of a WRDA that is still in committee).

- declares a national interest in conservation of existing supplies and development of new supplies.
- federal construction and assistance in the repair and improvement of existing water supply systems.
- federal construction of single and multiple purpose water supply projects.
- includes conservation measures and supply, treatment, conveyance, and distribution facilities.
- repayment under the provisions of the Water Supply Act of 1958 (authorized to recommend modified cost sharing for rural communities of less than 15,000).
- individual project feasibility studies and construction authorization.

S 560 National Water Supply Act of 1979

- studies of water supply projects (storage and desalination) and conveyance facilities
- regional and local water supply projects
- Corps construction and operation of projects
- repayment over 50 years at Water Supply Act of 1958 interest rate

S 728 Small Town & Rural Community Water Supply Assistance Act of 1979

- planning assistance to rural water associations serving less than 10,000 people (100% federal cost)
- design most efficient and economical water system (100% federal cost)
- construction of water supply projects (50% federal cost)

The impact of such changes would be to extend the direct federal assistance role into all facets of water supply augmentation, treatment and distribution. The Administration has already expressed serious concern about such provisions.

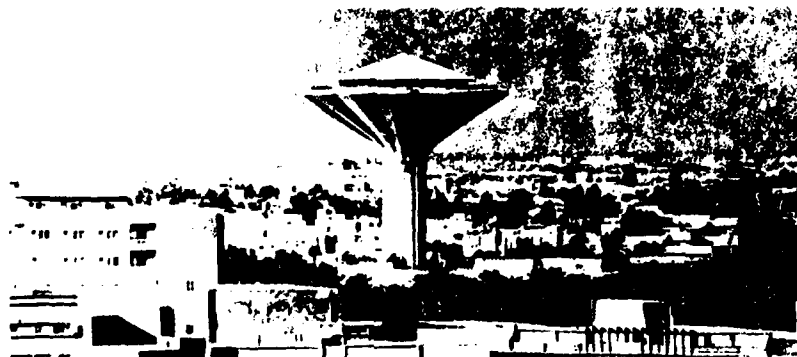
SUMMARY

The water resources program of the Corps of Engineers has made a tremendous amount of water supply storage available to non-federal interests. About 8 million acre-feet (10 billion cubic meters) of storage is under contract and another 12 million acre-feet (15 billion cubic meters) is part of existing and authorized projects. The President's declaration of a national emphasis on water conservation has resulted in changes in water supply planning that will improve the Nation's economic welfare and enhance its environment. The Corps has set forth a definition, principles, and procedures for evaluating water conservation that will ensure consistent and balanced treatment of water conservation and supply augmentation. The Corps is implementing a plan of action that will integrate water conservation into all aspects of its civil program. The water resources program is seldom static, and active consideration is being given to potential changes in the federal role in water supply/conservation. The pressures to expand the federal role are being met with strong resolve by others to retain the present federal role. Additional time will be required before the complex critical issues associated with this question can be resolved and the federal role for the future established.

APPENDIX 1 - References

1. Baumann, D.D., et al., "An Annotated Bibliography on Water Conservation," Contract Report 79-3, U.S. Army Engineer Institute for Water Resources, Fort Belvoir, Va., Apr., 1979.
2. Baumann, D.D., et al., "The Role of Conservation in Water Supply Planning," Contract Report 79-2, U.S. Army Engineer Institute for Water Resources, Fort Belvoir, Va., Apr., 1979.
3. Baumann, D.D., Boland, J.J., and Sims, J.H., "The Evaluation of Water Conservation for Municipal and Industrial Water Supply - Procedures Manual," Contract Report 80-1, U.S. Army Engineer Institute for Water Resources, Fort Belvoir, Va., Apr., 1980.
4. "Urban Water Systems: Problems and Alternative Approaches to Solutions," Subcommittee on Urban Water Supply of the President's Intergovernmental Water Policy Task Force, June 6, 1980.

Urban Water Supply Planning



by Duane D. Baumann and John J. Boland

Throughout history, concentrations of population have always been associated with large-scale water supply facilities. In the Middle East, in Central America, in the American Southwest—long-extinct civilizations have left evidence of their dependence upon water supply. The Sanitary Revolution of the late 19th and early 20th centuries, by insuring the safety and palatability of urban water supplies, only increased the dependence of urban civilization on water. The dependence is no less evident today. However, as the water and other resources of the United States are more widely and intensively known, the efficiency with which they are used becomes of greater concern.

Unlike the past, present urban water supply planning is a drastically different, challenging, and complex task. Traditionally, the planning process started by projecting the population to be served, estimating per-capita water use, and then simply multiplying one projection by the other to derive the future water use. Armed with an estimate of future water need, the problem was to identify adequate and available sources of supply, usually additional reservoirs and/or well fields.

However, the problem today is not solely an inadequacy of supply; instead a wide range of factors have an influential and important role in the planning and management of our urban water resources. Consequently, new techniques of planning and methods of evaluation will need to be developed. In addition, water management policies and practices will be modified. As early as 1973, the U.S. National Water Commission noted that:

"To increase efficiency in water use and to protect and improve its quality, and to do these things at least cost and with equity to all parts of the country . . . require major changes in present water policies and programs."

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Since 1973, there have been substantial changes in the process of planning and management of our urban water resources. For example, the U.S. Federal Water Resources Council has developed and recently revised the *Principles and Standards for Planning Water and Related Land Resources* and the U.S. Army Corps of Engineers has implemented new guidelines, such as the *Planning Process: Multiobjective Planning Framework*, and developed environmental impact analyses for proposed projects.

Concurrent with changes in the planning process has been a shift in perspective, that is, to a broader range of alternatives. The traditional response to increasing demand for water has been the development of additional supply. Those alternatives, for example, that would modify demand have been generally ignored. Similarly, this reliance upon technologies to increase supply, instead of policies to modify the schedule of demand, has been evident in another water resource problem—flood control.

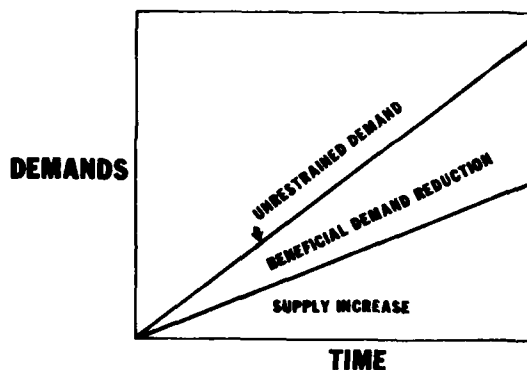
In planning for urban water the challenge is to determine the optimum combination of all alternatives to balance the supply and demand. Not only are the alternatives that increase supply considered, but those options that modify the demand for water are also evaluated, such as water conservation.

Water Conservation: Renewed Prominence in the 1980s

The first indication of widespread interest in urban water conservation appeared shortly after 1970. The National Water Commission conducted a study of the potential for water use reduction through conservation practices, including pricing policy, and discussed water conservation as an alternative to, or adjunct of, water supply augmentation. Some urban water suppliers began to encourage conservation practices by their customers (for example, Washington Suburban Sanitary Commission, *A Customer Handbook on Water-Saving and Wastewater Reduction*, 1972). Further attention to water conservation grew out of the realization that reduced water use may result in reduced sewer flows. The Clean Water Act of 1977 specifically requires measures to reduce wastewater

flows as a condition of eligibility for wastewater treatment facility construction grants.

It may appear puzzling to some why conservation has gained national prominence in light of the current and future patterns of water use. For example, according to the U.S. Water Resources Council, Second



National Assessment, the amount of withdrawal¹ in the U.S. is expected to decline from 1975 levels by nine percent by the year 2000. This phenomenon is caused primarily by industrial water use which is expected to decrease 62 percent over this time period.

Recycling, which already has a significant effect in the reduction of industrial water use, and water use efficiencies are expected to exert an increasingly important role in projected water use. Hence, the national emphasis on water conservation is already reflected in the projections of water use.

However, the rationale for considering water conservation in water supply planning is not solely a function of the relationship between supply and projections of use; other factors today impinge upon the efficiency of water use and planning to meet future demand. Data on national aggregate water use have little relevance because urban water supply planning is a local phenomenon. It is at the local level where the

¹Withdrawal of water is that amount taken from a surface or groundwater source. Consumptive use is that portion of withdrawn water not returned to the source.



range of factors that determine the efficiency of water supply production is of most interest.

There are primarily six forces that influence urban water supply planning today. First, there are environmental constraints in the procurement of additional supply; new reservoir sites have become increasingly scarce, and groundwater resources are becoming inadequate to meet the demands of urban areas. Gilbert White has noted the depletion of groundwater as one of the six most important water resource problems in the world, and particularly in the United States. A second set of problems that constrain urban water resource planning is the existence of new laws and regulations; political, legal, and institutional problems of interbasin transfers have proliferated until it is nearly impossible to plan for a transfer of water from one basin to another. Third, the concern for water quality, which mushroomed during the 1970s, has significantly constrained the opportunities in urban water management. Water quality standards have been established by passage of the Federal Water Pollution Control Act Amendments (1972), the Safe Drinking Water Act of 1974, and the Clean Water Act of 1977. Fourth, the costs of energy have increased at record rates and resulted in substantial increases in water rates. Fifth, an additional factor in the increased costs of water resource development since the early 1970s is the cost of money, which this year has witnessed a record high prime interest rate of 20 percent. Finally, increasing urbanization, especially those experiencing a growing population, and the demand for water continues to rise.

Water Policy Reform: Federal Response

Water conservation became an integral part of national water policy in 1978, when President Carter, in his Water Resources Policy Reform Message of June 6, 1978, stated:

"Managing our vital water resources depends upon a balance of supply, demand, and wise use. Using water more efficiently is often cheaper and less damaging to the environment than developing additional supplies. While increases in supply will still be necessary, these reforms place emphasis on water conservation and make clear that this is now a national priority."

Moreover, President Carter's Water Policy Message not only called for a new national emphasis on water conservation, but required all Federal agencies to in-



Often, environmental constraints limit additional supply development.



corporate water conservation requirements in all applicable programs, and set forth a program which would provide states with financial assistance in planning for water conservation. Water conservation has been declared one of the priority areas to receive support from the U.S. Office of Water Research and Technology.

A recent GAO report underlines President Carter's Water Policy Message recommendations that call for increasing technical assistance for water conservation by farmers and urban dwellers and solving constraints that prevent or impede the implementation of better water management and conservation practices. In a related report, the GAO concluded that a major constraint to the implementation of the available conservation measures was the lack of knowledge about their effectiveness.

The expectation of these national efforts is that water conservation programs will contribute significantly to solving our national urban water resource management and planning problems by:

- making available additional water supply for other uses;
- obviating or delaying the construction of expensive additions to supply;
- reducing the size or delaying the construction of wastewater treatment facilities; and,
- reducing the financial costs and energy requirements for the procurement, production, and distribution of water supply and the treatment of wastewater, especially important since the passage of the Clean Water Act of 1977.

In response to the President's Message, the Corps of Engineers intensified its efforts to incorporate water conservation into the Civil Works program. In 1978, research was undertaken to develop appropriate methodology. The first effort was a survey and appraisal of the available information about water conservation. In order to provide initial and readily available information to Corps' planners, a selection was made of the literature reviewed and was subsequently

published as an annotated bibliography.² From the experience and data base, critical questions were raised, and deficiencies and essential needs were identified. Specifically, these were:

- What is conservation?
- What is the effectiveness of available conservation measures?
- What are the principles for evaluation of water conservation measures for municipal and industrial water supply?

*The Role of Conservation in Water Supply Planning*³ addressed these questions. A precise and practical definition was formulated, estimates of the effectiveness of conservation measures were identified and appraised, and a methodology was developed not only to evaluate specific conservation measures but to integrate measures into water supply plans.

The next task was to develop a manual for the evaluation of water conservation for municipal and industrial water supply. *The Evaluation of Water Conservation for Municipal and Industrial Water Supply: Procedures Manual*⁴ includes a description of the concepts, procedures, and techniques of measurement for developing and evaluating water conservation proposals for municipal and industrial uses of water.

The objective of the Procedures Manual is to integrate water conservation planning with water supply planning in a logical, consistent manner. The gap between future demand and supply may be reduced by water supply augmentation, by water conservation, or, and more likely, by a combination of the two approaches.

What is Conservation?

Before any attempt can be made to determine whether conservation should or should not be implemented, a clear, precise, and practical definition

²An Annotated Bibliography of Water Conservation, IWR, Water Resources Support Center, Ft. Belvoir, VA 22060.

³Are available from the same address cited in footnote 2.



— Properly applied conservation measures may enhance environmental quality through instream flows for fishing, boating and swimming.

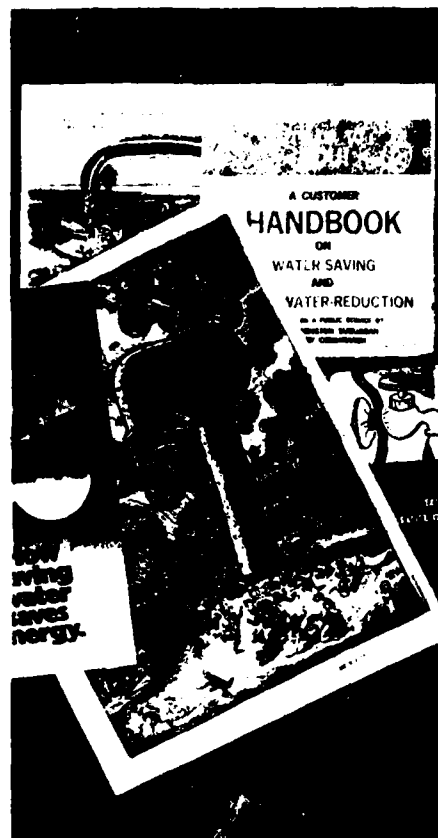
of conservation is required. Most past definitions of conservation have not been precise and consequently were not easily translated into policy. For example, to some the concept of conservation may mean a reduction in use, to others a development of new supplies, and to others the restriction of specific uses of water.

The most common definition of conservation was provided by Gifford Pinchot, considered by many as the Father of Conservation, who stated that "conservation is the use of natural resources for the greatest good of the greatest number for the longest time." Yet, to the planner who must formulate and evaluate water conservation measures, how does such a definition help? What is the greatest good? How should it be determined? Who determines what the greatest good is? Is the greatest good achieved by always striving to reduce water use? Who are the greatest number? How far into the future can we hope to plan?

In response to the President's Policy Reform Message several definitions of conservation were established by numerous groups. In a report by the U.S. Department of Interior, the objective of conservation was defined as "the wise and judicious use of available supplies." But, what does wise and judicious mean? Similarly, the ad hoc Committee on Water Resources, Commission on Natural Resources of the National Academy of Sciences, failed to distinguish between those actions or policies that qualify as conservation and those that are simply efficient water management strategies.

Comprehensive water supply planning requires the evaluation of three basic sets of considerations, including the merits of demand reduction practices; the potential for more efficient utilization of existing supplies; and the need for new supplies. The first two categories, which are demand management strategies, are included within the definition of water conservation.

But, should all measures that reduce water use or loss be implemented? And if so, to what extent, that is, how much curtailment of water use? The answer is quite clear and precise. Only those measures that re-



duce the use, or loss, of water without disproportionately increasing the use of other resources can qualify as conservation. For each measure the total beneficial effects of the reduction in water use and/or water losses must be greater than total adverse effects.

Water conservation, then, is defined as "any beneficial reduction in water use or water loss." A water management practice qualifies as a conservation measure when it passes two tests:

- It conserves a given supply of water by reduction in water use or water loss.
- It results in a net increase in social welfare.

More specifically, the first criterion states that implementation of a water management practice must result in water use (or loss) which is less than it would have been had the measure not been implemented. The end result is in the reduction of water use or loss so that a segment of existing or future water supply is available for uses that otherwise would not have been served except by the provision of new supplies.

The second criterion is that the reduction in water use or loss must be beneficial. That is, in order to qualify as a conservation measure, implementation must result in a net positive contribution to the Natural Economic Development objective, the Environmental Quality objective, or both.

Types of Conservation Measures

Water conservation measures have been classified as (Table I):

- Regulatory practices;
- Management practices; or
- Education efforts.

The regulatory practices are those measures that are dictated by local, state, or Federal legislation. In general, these measures would likely carry penalties or sanctions for noncompliance, e.g., local requirements of low-flush toilets in new dwelling units.

Management practices are those implemented by the local water utility or by the responsible units of

government that result in a beneficial reduction in water use or water losses. These include measures such as leak detection, metering, or modification of pricing policies.

Educational campaigns are directed toward voluntary beneficial reductions in water use or losses. For example, information on conservation efficiency in lawn sprinkling may result in a reduction of lawn water use without damage to lawns.

How Effective are Conservation Measures?

It is not uncommon to read about enormous reductions in water use for a specific community attributed to conservation. For example, Schoenfeld's study in Rhode Island noted that municipal water use can be reduced during periods of shortage by 35 percent without drastically changing life styles.

How useful are such estimates in assessing the role of conservation in urban water resource planning? The authors believe such estimates are of little value and frequently misleading.

Based upon a review of the literature, the major conclusion about the effectiveness of water conservation measures is that comparatively little is known. Concerning information about the probable adoption of voluntary conservation measures, there is even less.

There are two major reasons for the variation in estimates of the effects of specific water saving strategies. First, many estimates are applicable only for the conditions at the sites from which they were derived. Second, the studies to estimate effectiveness may be poorly designed, leading to erroneous conclusions.

Clearly, during a prolonged drought residents are more likely to employ water reducing devices than during average or wet years; hence, estimates on effectiveness measures during drought cannot be assumed to be applicable during nondrought years.

However, most of the estimates of effectiveness have been derived during periods of drought. This is particularly true today concerning the recent California drought. In addition to drought, average weather (climate) varies from place to place and is an important determinant in water use and therefore on the effectiveness of water conservation measures. Similarly, the

REGULATIONS	MANAGEMENT	EDUCATION
<p>Federal and State Laws and Policies</p> <ul style="list-style-type: none"> A. Presidential Policy B. PL 92-500 C. Clean Water Act Amendment 1977 D. Safe Drinking Water Act <p>Local Codes and Ordinances</p> <ul style="list-style-type: none"> A. Plumbing Codes for New Structures B. Retrofitting C. Sprinkling Ordinances D. Changes in Landscape Design E. Water Recycling <p>Restrictions</p> <ul style="list-style-type: none"> A. Rationing <ul style="list-style-type: none"> 1. Fixed Allocation 2. Variable Percentage Plan 3. Per Capita Use 4. Prior Use Basis B. Determination of Water Use Priorities <ul style="list-style-type: none"> 1. Restrictions on Public and Private Recreational Uses 2. Restrictions on Commercial and Institutional Uses 3. Car Wash Restrictions 	<ul style="list-style-type: none"> A. Leak Detection B. Rate Making Policies <ul style="list-style-type: none"> 1. Metering 2. Pricing Policies <ul style="list-style-type: none"> a. Marginal Cost Pricing b. Increasing Block Rate c. Peakload Pricing d. Seasonal Pricing e. Summer Surcharge f. Excess Use Charge C. Tax Incentives and Subsidies 	<ul style="list-style-type: none"> A. Direct Mail B. News Media C. Personal Contact - Speaker Program D. Special Events - School Programs

socio-economic conditions within each community which influence the effectiveness of water conservation vary markedly. Is the community primarily residential or is there significant industrial and commercial water use? What is the price of water? What is the income of the customers? What is the lawn size of the residential customers? In order to calculate more precise estimates of water use reduction, community water use must be disaggregated and relevant information on the charac-

teristics of each user class must be obtained to derive more precise estimates of effectiveness. Finally, there is little or no information about the factors affecting the adoption of voluntary water conservation measures. The results of educational campaigns are usually based upon communities under crisis conditions, such as drought. Clearly, additional research is required to determine the factors that affect consumer adoption of water conservation measures during noncrisis situa-



— Conserving water makes the scarce resource available for a multitude of uses.

tions such as the current studies funded by the U.S. Office of Water Resources and Technology. Such information will be useful in estimating the effects of proposed measures and in the formulation of a cost-effective educational campaign.

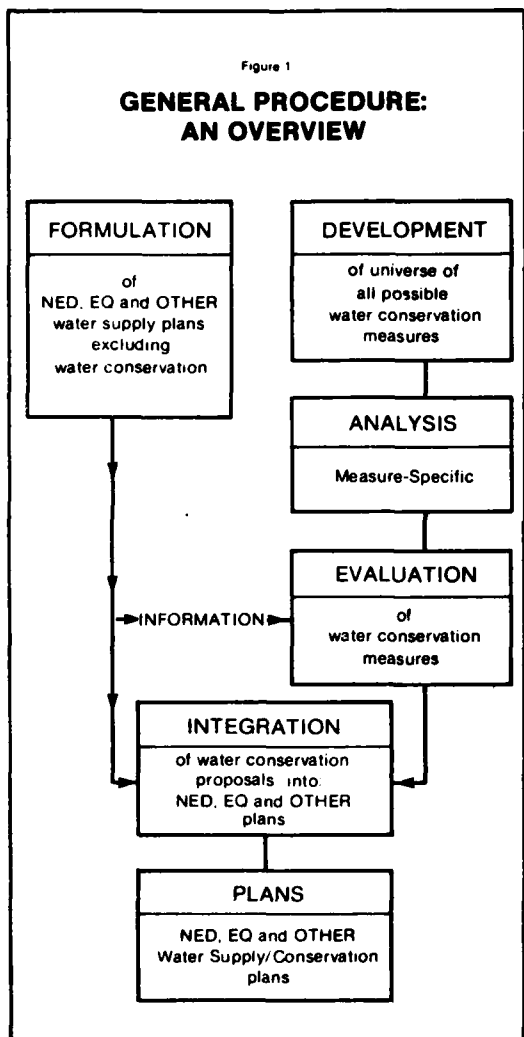
Conservation in Water Supply Planning

The extent to which water conservation measures should be included in a particular water supply plan is determined by testing each possible measure against that plan, and identifying and measuring advantageous and disadvantageous effects. The Procedures Manual describes this process, which consists of three phases:

- Measurement specific analysis, which is independent of the characteristics of the water supply plant(s);
- Evaluation of conservation measures, which incorporates the characteristics of the water supply plant(s); and
- Integration of the water conservation measures into the water supply plant(s), forming the final water supply conservation plant(s).

The procedure is shown in Figure 1. Prior to initiating the first phase, a list of all possible water conservation measures is developed, including those based on regulation, management actions, and educational efforts.





SUMMARY

Water conservation is the **beneficial** reduction in water use or in water losses. It is important to reemphasize that water conservation according to this definition is neither a new nor a different water management technique. Instead, water conservation practices are merely a **subset** of all alternatives that comprise efficient management of water resources.

The challenge for the planner is to consider the efficient allocation of the water resource at every stage of distribution and use. Among the desirable practices are some which involve beneficial reductions in the use of water or in water losses; it is these practices that in our judgment are water conservation. The cautions of measuring the effectiveness of potential water conservation measures have been discussed; and, the methodology to assist the planner in evaluating water conservation measures for possible integration into water supply plans has been developed and been briefly described. ■

A PROCEDURES MANUAL FOR EVALUATING WATER CONSERVATION PLANNING

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INTRODUCTION

In the past few years, the role of water conservation in the management and planning of water resources has become increasingly important. A number of factors account for this emphasis: (1) new reservoir sites have become increasingly scarce; (2) concern for environmental quality has grown; (3) groundwater resources are increasingly inadequate to meet the demands of urban areas; (4) political, economic, and institutional problems of interbasin transfers have proliferated, making it nearly impossible to plan for transfer of water from one basin to another; (5) the costs of water resource development have risen enormously in the last decade as a result of the increase in the price of energy, the increase in the cost of money, and the rise in water quality standards as manifested in the passage of Federal legislation such as the Federal Water Pollution Control Act Amendments (1972), the Safe Drinking Water Act of 1974, and the Clean Water Act of 1977; and (6) the demand for urban water has continued to increase. In combination, these factors have created a situation which directs attention to the possibilities of water conservation.

The Corps of Engineers recognized these trends and began policy studies and research early in 1978 to define and integrate water conservation into its Civil Works program. This paper presents one of the major outputs of this research effort and discusses how the Corps views water conservation.

WATER CONSERVATION?

Water is an essential resource. It is important in everything we do—food and fiber, production, energy, pollution control, transportation, environmental quality—and the list goes on. Along with this, the growing scarcity of water is well documented. Cost efficient and environmentally sound water conservation measures offer an excellent opportunity to meet growing future demands for water dependent goods and services. Used in conjunction with traditional water supply development and more efficient use of existing supplies, our limited water resources can be stretched to meet ever growing demands.

To most people, water conservation is a noble and laudable goal, but in the formulation and implementation of water conservation policies a formidable obstacle is encountered: "What exactly is water conservation?"

Water conservation is not a new term; however, its use has been so varied that a universal definition has not evolved. Water conservation is different from other forms of conservation. Energy conservation is usually thought of in terms of non-use so that the resource will be available at a future time. Fish and wildlife conservation provides for use of the resource, but in a manner that preserves and protects the regenerating capability of the resource. Non-use of water does not automatically insure its availability at a later time, and the regenerating process (hydrologic cycle) is pretty much beyond our ability to manage at this time.

Since the historic 1908 Governors Conference in Washington, D.C., the term conservation has been subject to many interpretations. Gifford Pinchot, considered by many to be the father of the conservation movement in this country, stated that "conservation is the use of natural resources for the greatest good of the greatest number for the longest time."

Critical analysis of this definition, however, appealing the prose, concludes that it fails as an operational definition. It does not serve as a guide to the formulation of national policy.

Historically, many other definitions have emphasized the wise and judicious use of available supplies, but few distinguished between water conservation and comprehensive, efficient water supply and demand management.

In summary, many past definitions leave something to be desired; while laudably comprehensive, they lack precision. Consequently, the Corps of Engineers developed a water conservation definition and evaluation process that emphasizes a balanced approach to analyze both supply and demand management on a similar basis. This will permit a consistent trade-off between increments of new supply, water conservation measures, and measures that result in more efficient use of existing resources.

WATER CONSERVATION DEFINED

To be helpful, the Corps' definition possesses two attributes: (1) it is precise; and (2) it is practical, and it considers conservation as management of the demand function. Therefore, the Corps' definition is as follows: "Water conservation is any beneficial reduction in water use or in water losses."

Based on this definition, water management practices constitute conservation only when they meet two tests: (1) their purpose is to

conserve a given supply of water through reduction in water use (or water loss); and (2) their total national economic and environmental benefits outweigh their total national economic and environmental costs.

Water use is the withdrawal of water from a supply or other action which denies the availability of that water to another user. Uses range from human consumption to support of fish and the natural environment associated with streams. A reduction in water use is beneficial if the aggregate of all beneficial economic and environmental effects resulting from implementation of the water management practice exceeds the aggregate of all adverse economic and environmental effects occasioned by such implementation. Recognizing that just as in the case of augmenting supply, conservation measures may deplete other scarce resources (such as energy), the above definition of beneficial reductions assures that all scarce resources are conserved.

Water supply and water conservation, as defined above, have much in common. Neither can be implemented without making demands on other scarce resources, and the merits of both must be evaluated using the same basic criteria. In addition, the fact that not all new supplies should be considered desirable is also applicable to water conservation measures. The evaluation of the adequacy of existing water supplies and the measures needed to address future water needs require an assessment of: (1) demand reduction practices; (2) more efficient utilization of existing supplies; and (3) need for new supplies.

EVALUATION PROCEDURE

The Corps of Engineers has developed a procedures manual (The Evaluation of Water Conservation for Municipal and Industrial Water Supply: Procedures Manual), detailing an evaluation process that permits a consistent and balanced trade-off between water conservation and increments of new supply.

Figure 1 presents an overview of the general evaluation procedure indicating that simultaneous evaluations can be made of both the supply and conservation options.

Water supply plans are formulated according to existing procedures without consideration of additional water conservation measures.

Water conservation measures are identified by the measure-specific analysis. These individual measures are then evaluated against alternative water supply plans. Based on this evaluation, water conservation proposals are developed which can be integrated into water supply plans, yielding alternative water supply/conservation plans.

GENERAL PROCEDURE : AN OVERVIEW

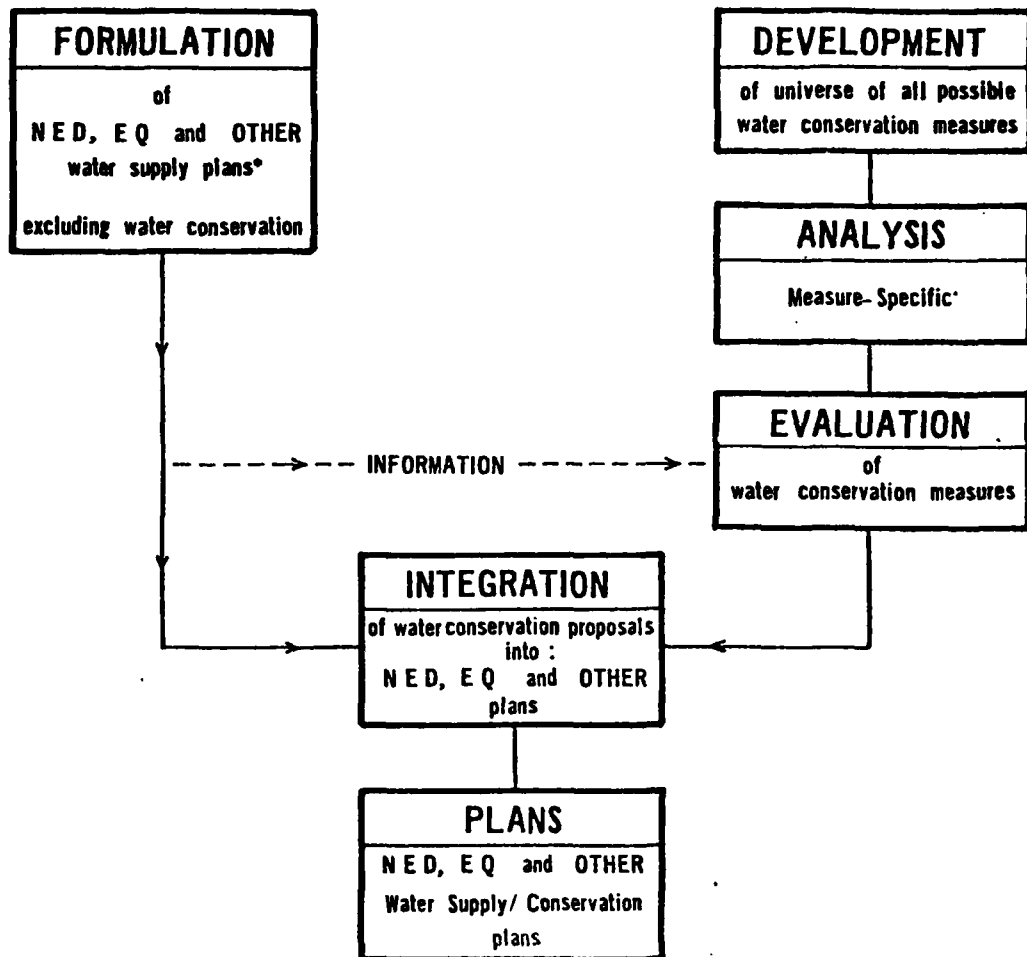


FIGURE 1

* Water supply plans may also be the water supply portion of a multi-purpose plan.

DEVELOPMENT

The evaluation of water conservation starts with the development of a universe of possible water conservation measures (regulation, management, and education, as shown in Table 1). These measures are then tested for applicability, technical feasibility, and social acceptability. The potential measures are those that are applicable to the study area and setting, are technically feasible, and have potential for being socially acceptable.

MEASURE-SPECIFIC ANALYSIS

A measure-specific analysis, as shown in Figure 2, establishes the characteristics of the measures that are independent of the water supply plans. These include the implementation conditions (coverage and duration), the effectiveness of the measures, the costs foregone for water supply, energy savings, the costs foregone for treatment of raw water and wastewater, implementation costs, and environmental effects.

EVALUATION OF WATER CONSERVATION MEASURES

Other positive and negative effects of substituting a water conservation measure for an equivalent amount of water supply are dependent upon the specific water supply plan considered. To test all potential measures and combinations thereof for inclusion in several supply plans requires an inordinate number of calculations. The procedure outlined in Figure 3 was developed which reduces the number of calculations, yet retains acceptable limits of accuracy. The procedure is to include each potential measure in the water supply plan, one at a time, to determine the net change in outputs of the plan that are attributable to that measure. The measures are then ranked in merit order based on their net increase in the desired output. For example, the measure that produces the largest increase in net economic benefits is ranked first for that process of integrating water conservation into the plan. Other measures would be ranked according to their impact on net benefits. The same ranking procedure would apply to the environmental quality with net positive impacts on the environment being the ranking factor.

INTEGRATION OF WATER CONSERVATION INTO WATER SUPPLY PLANS

The ranking of measures in merit order permits a once-through process for integration of the water conservation measures into the water supply plans to produce plans that maximize the desired outputs. This procedure is shown in Figure 4.

The maximization of outputs is accomplished by substituting the measure ranked first in merit order for an equivalent amount of water supply. The increase in net beneficial effects of the plan is then calculated. The second measure in merit order is then substituted

Table 1. Illustrative List of Water Conservation Measures

REGULATIONS	MANAGEMENT	EDUCATION
Federal and State Laws and Policies	A. Leak Detection	A. Direct Mail
A. Presidential Policy	B. Rate Making Policies	B. News Media
B. PL 92-500	1. Metering	C. Personal Contact
C. Clean Water Act Amendment 1977	2. Pricing Policies	-Speaker Program
D. Safe Drinking Water Act	a. Marginal Cost Pricing	D. Special Events
Local Codes and Ordinances	b. Increasing Block Rate	-School Programs
A. Plumbing Codes for New Structures	c. Peakload Pricing	
B. Retrofitting	d. Seasonal Pricing	
C. Sprinkling Ordinances	e. Summer Surcharge	
D. Changes in Landscape Design	f. Excess Use Charge	
E. Water Recycling		
Restrictions	C. Tax Incentives and Subsidies	
A. Rationing		
1. Fixed Allocation		
2. Variable Percentage Plan		
3. Per Capita Use		
4. Prior Use Basis		
B. Determination of Water Use Priorities		
1. Restrictions on Public and Private Recreational Uses		
2. Restrictions on Commercial and Institutional Uses		
3. Car Wash Restrictions		

MEASURE – SPECIFIC ANALYSIS

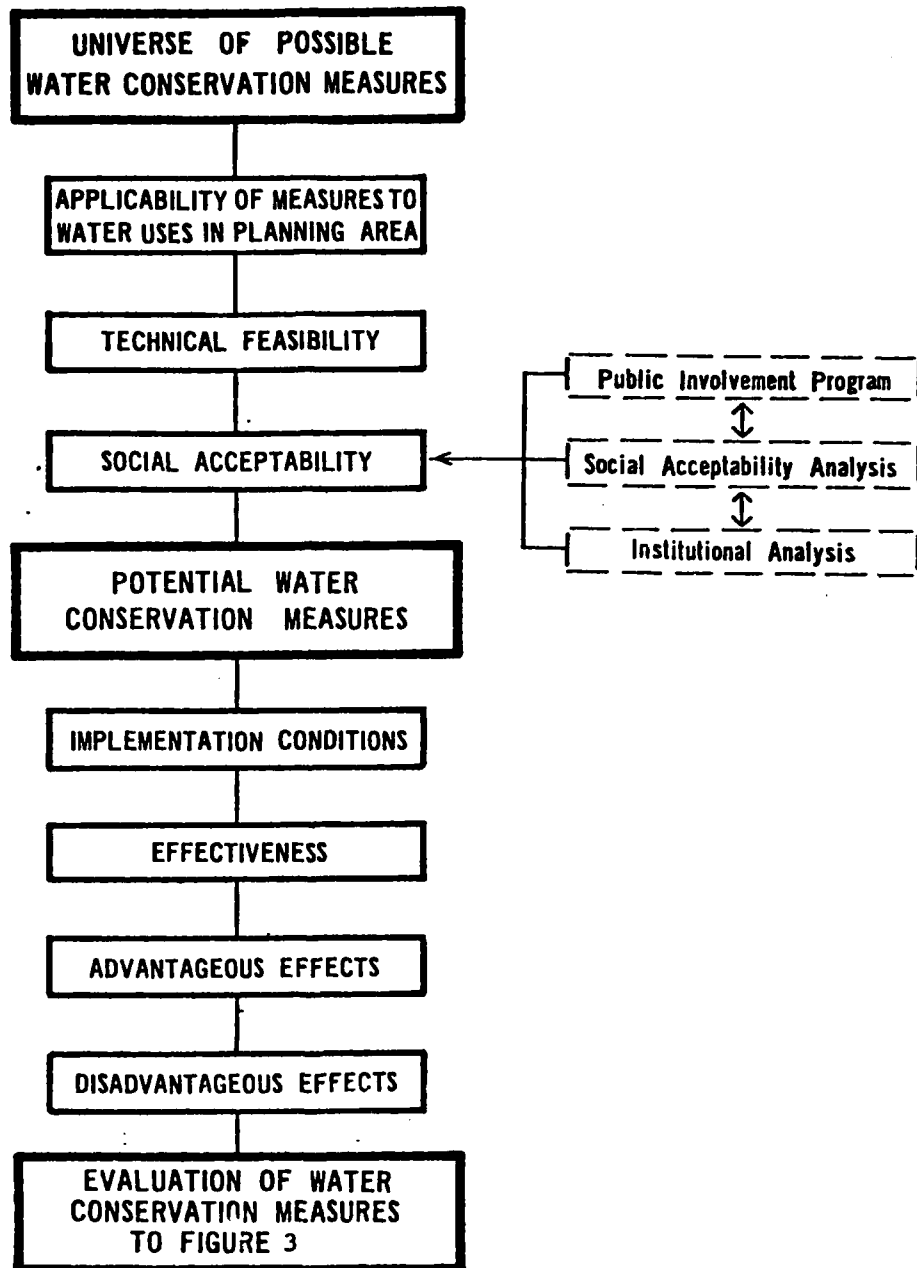


FIGURE 2

EVALUATION OF WATER CONSERVATION MEASURES

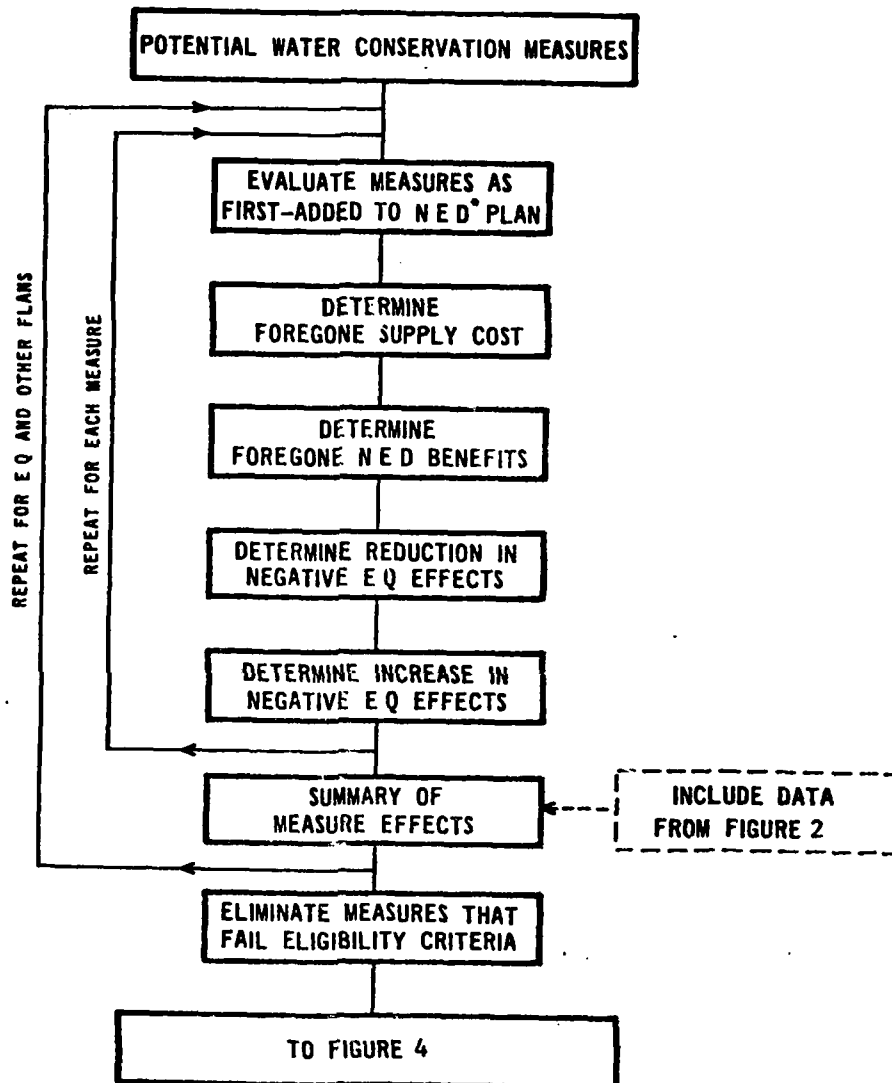


FIGURE 3

* NED, EQ or Other as appropriate.

INTEGRATION OF WATER CONSERVATION INTO WATER SUPPLY PLANS

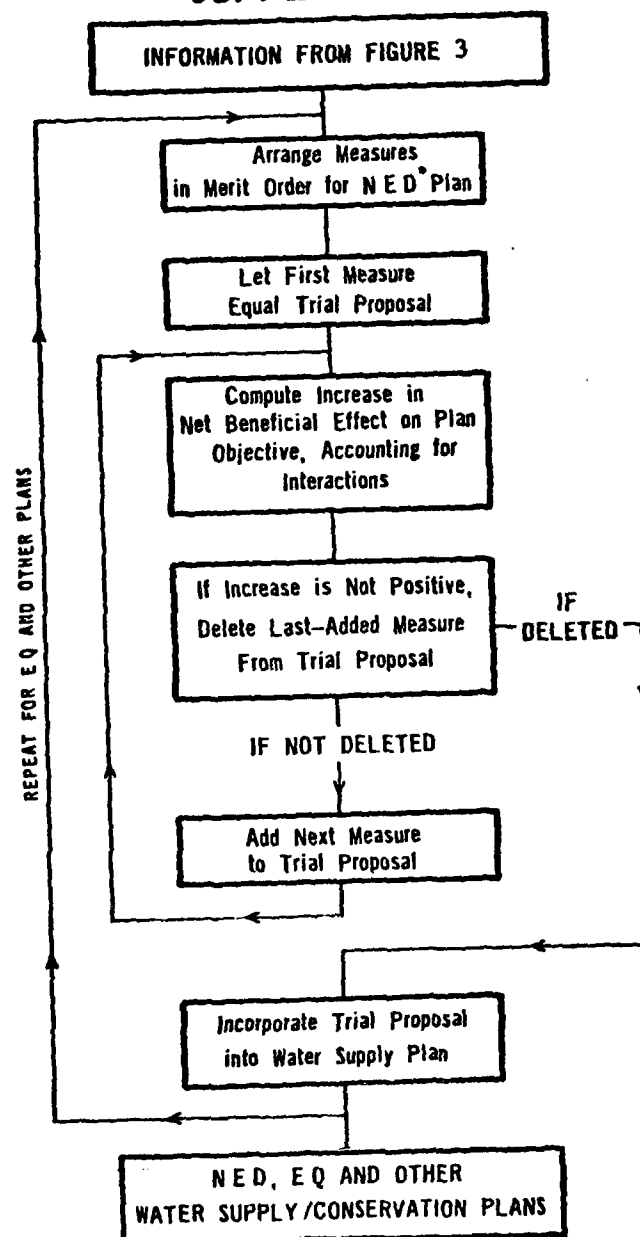


FIGURE 4

* NED, EQ or Other as appropriate.

after careful consideration of the interactions between the first and second measures. When interactions exist, the incremental effect of the second measure will probably be less than its effect as a single measure. This procedure continues until the addition of another measure reduces the net beneficial effects on the plan objective. For the NED plan, measures are added until the next measure would reduce the net NED benefits of the plan. The resulting plan represents the NED plan for water supply/conservation.

Finally, the water supply/conservation plans should be tested for compliance with the desired system reliability. Dependability can be designed into plans that include water conservation in the same way that it is included in plans for water supply.

APPLICATION

The Corps of Engineers has developed a methodology to evaluate water conservation in its planning process. Obviously, this type of research must now be tested, evaluated, and communicated to the users in the field districts and changed if necessary.

To accomplish this objective, continuing research will be conducted to refine and clarify portions of the manual, such as the more longer term effects of specific conservation measures and data availability. Specific case studies are being conducted or planned where close coordination and specific guidance can be given by IWR personnel to fully test the procedures manual. Workshops are being planned to impart the principles of the manual to the Corps field personnel who will actually be conducting the studies, and additional policy studies and guidance (such as advancing the state of the art in dealing with groundwater conjunctive use and improving forecasting methodologies) are planned to further develop the Corps' role in water conservation planning.

SUMMARY

Water conservation has taken on an increasingly important role in Federal water policy these past few years. The Corps of Engineers has met the challenge to fully integrate water conservation into its Civil Works program. The Corps defined water conservation in such a way that the definition is both precise and practical. Along with this definition, a procedure was developed that permits an evaluation of water conservation where consistent trade-offs between increments of new supply and measures that result in more efficient use of existing supplies can be made. This procedure encompasses four basic steps: (1) the development of a universe of possible water conservation measures; (2) a measure-specific analysis which is independent of the water supply plan(s); (3) an evaluation of conservation measures incorporating the characteristics of the water supply plan(s); and (4) the integration of the water conservation measures into the water supply plan(s) to form the final water supply/conservation plan(s).

Continuing Corps research will further refine and enhance the Corps involvement in water conservation planning.

URBAN WATER SUPPLY

URBAN WATER SYSTEMS:
PROBLEMS AND ALTERNATIVE APPROACHES TO SOLUTIONS

Presented By:
Kyle E. Schilling

Presented To: Annual Conference of the New England Water Works Association
22 September 1980

This presentation summarizes the results of the work of the Subcommittee on Urban Water Supply of the President's Intergovernmental Water Policy Task Force. The work described is a direct result of the President's Water Policy message of June 6, 1978 which created an intergovernmental Task Force, chaired by the Secretary of the Interior, Cecil Andrus. The Task Force membership includes Federal, state, county and city officials. The Subcommittee on Urban Water Supply formed by the task force is chaired by the Assistant Secretary of the Army for Civil Works, Michael Blumenfeld. Pursuant to its charter, the Subcommittee has:

- o Commissioned an inventory of existing Federal programs which either presently assist or have the potential of assisting urban water system rehabilitation or new construction;
- o Identified and evaluated institutional and financial problems surrounding supply and distribution of municipal water; and
- o Identified and assessed policy and program changes at the Federal, state and local level in order to address the problems.

Based on this work, the Subcommittee made findings and developed alternative policy approaches, as set forth below.

Findings

The principal findings of the Subcommittee are that:

- (1) Urban water system capital expenditures needed over the next 20 years are estimated to total \$75-\$110 billion. This includes replacement and rehabilitation of distribution and treatment systems at \$50-\$80 billion, servicing growth at \$5-\$8 billion, upgrading to improving drinking water quality at \$425 million, and new source development at \$20-\$25 billion.*
- (2) Rough estimates suggest that as many as two out of ten urban water systems might experience capital investment shortfalls over the next 20 years. An investment shortfall is that portion of the capital investment estimated to be needed which a system is judged unable to finance based on its projected expenditures and on revenue increases up to a doubling of rates. The historical significance of such a ratio of shortfall is unknown.

*All figures are in 1979 dollars. No adjustments have been made for inflation.

- (3) The most probable estimate of urban water system capital investment shortfall over the next 20 years, based on rough order-of-magnitude estimating techniques, is between \$10-\$13 billion. The shortfall could range between \$5-\$26 billion, since estimates are both difficult and uncertain without a city-by-city analysis.
- (4) Of the total estimated national shortfall, about one-half is attributed to distribution system needs and one-third to new source development needs.
- (5) Municipally-owned and operated water systems are four times as likely as privately-owned systems to experience shortfalls. Regional public systems are twice as likely to experience shortfalls as private systems. Publicly-owned systems currently account for 73 percent of all urban systems and serve 81 percent of the population of urban areas.
- (6) Federal categorical programs which supply assistance specifically for water supply purposes have limited applicability to urban water supply problems. Farmers Home Administration programs are focused on communities smaller than those classed here as urban (over 50,000 population). Federal water resource development agency programs of direct construction, by policy, do not develop projects for single purpose water supply.
- (7) Some Federal assistance programs do provide substantial sources of funding assistance which could be directed to water supply. Use of such assistance for water supply purposes depends upon whether state and local governments are able to give such use a high priority relative other needs for the funds. Economic Development Administration programs, HUD community development programs and Treasury's General Revenue sharing programs provide very large resources which could be used for water supply purposes. In FY 1977, nearly \$10 billion went to state and local governments from these programs; about two percent of these funds appear to have been allocated to water supply purposes. Of the \$10 billion total, only \$6 billion was available to urban areas (cities over 50,000). of which the amount utilized for urban water supply is unknown.

The table below shows the results of the Inventory of Federal programs providing funding assistance which could be directed to water supply.

INVENTORY RESULTS

FY 77 (MILLION \$)

<u>Programs</u> ¹	<u>Total Budget</u>	<u>Water Supply Portion</u>	<u>Percent of Total</u>
General Revenue Sharing	6,550	79	1.2
HUD	3,175	64	2.0
EDA	321	73	22.7
	10,046 ²	216	2

How you feel about the inventory results; depends in large measure on how you view the importance of the findings that 80% of the systems are not expected to experience shortfall compared to the 20% that are expected to experience shortfall over the next 20 years.

Given that some observers would view these findings and conclude there was not a problem and that others would conclude there was a problem; the subcommittee identified 1 status quo policy approach and 4 new initiative policy approaches.

These approaches are:

- (1) Status Quo - This approach would retain existing financial, regulatory, and institutional relationships to continue full local responsibility for water supply.
- (2) Modified Policies and Programs - Modify existing policies and programs to increase Federal technical and planning assistance and condition existing direct Federal, grant, and loan programs that are used for urban water supply on state review of urban water system utility rate and investment policies.
- (3) Federal/State Water Banks - Create Federal/State water banks to make capital investment funds more easily accessible to urban water systems. Conditions would be attached to loans requiring

¹ Tax exempt bonds (subsidy effects) \$320 million (water and sewer)

² FY 77 funds available to urban areas \$6 billion

conservation to reduce future capital investment needs and to establish self-sustaining rates and investment practices. Interest subsidies also could be provided for particularly distressed urban areas.

- (4) Financial Assistance - Implement increases in existing programs or add new programs of Federal financial assistance providing grants, loans or loan guarantees, conditioned upon the establishment of conservation programs to reduce future capital investment needs and establishment of self-sustaining rate and investment practices.
- (5) Single Purpose Water Supply - Remove existing policy prohibitions against single purpose water supply in Federal water projects and allow direct Federal construction of single purpose water supply projects. Change Federal policy to permit the inclusion in Federal projects of wellfields, purification and distribution facilities, as well as reservoir source development and major conveyance projects. Change Federal policy to permit repair and rehabilitation, as well as major reconstruction of such facilities. States would determine, with local input, water supply priorities, and costs would be repaid over time in accordance with the 1958 Water Supply Act.

These alternative approaches are not mutually exclusive. The elements and condition of one approach can be combined with those of another. Furthermore, while the approaches are broadly illustrative of the possible range of approaches which might be considered, they do not exhaust all of the possibilities.

Finally, the subcommittee believes that selection and implementation of any one or combination of policy approaches by policymakers should occur in conjunction with a more detailed study of urban water resource problems to reduce uncertainties as implementation proceeds.

Such a study should address needs outlined in the Subcommittee Report and: (1) relate urban water supply problems and solutions to other urban infrastructure problems; (2) inventory on a case-by-case basis urban water system needs; and (3) provide a basis for review of, and "mid-course" correction to the approach or approaches selected.

In closing, I would like to say that the Subcommittee's report advances our understanding of (1) the "state of health" of the nation's urban water supply systems and (2) the range of alternative policy approaches available to address problems. Based, as it is, upon broad inputs from representatives of states and cities, as well as, Federal agencies, it should provide highly useful to the Administration, Congress and other interested parties as present policies are reassessed.

